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SMART MANUFACTURING: ROLE OF INTERNET OF THINGS IN PROCESS OPTIMIZATION

Master of Science thesis

Examiner: professor Miia Martinsuo
Examiner and topic approved by the Faculty Council of the Faculty of Business and Built Environment
on 9nd March 2016

ABSTRACT

PAYA GHASHGHAEE: Smart manufacturing: role of Internet of Things in process optimization
Tampere University of Technology
Master of Science Thesis, 86 pages, 0 Appendix pages
May 2016
Master's Degree Programme in Business and Technology
Major: Managing Technology-Driven Businesses in Global B2B Markets
Examiner: Professor Miia Martinsuo

Keywords: Internet of Things, RFID, production, optimization, shop floor, real-time information

This research is primarily focused on process optimization in manufacturing field in business-to-business context. The study is an effort to point out the issues manufacturers face at their shop floor and it provides solutions for dealing with those issues. During the last decade the Internet of Things (IoT) has gained a lot of attention from both academia and practitioners. IoT emphasizes on the importance of physical objects transferring information by using both software and the Internet. Based on the global trends, nowadays, there is a clear requirement for companies to focus on how they can implement IoT in order to facilitate their businesses and create new business and market opportunities. IoT is able to connect various things and objects around us which are able to interact with each other. In other words, IoT technologies not only connect a particular industrial system or supply chain, but also connects stakeholders and end-customers.

The goal of the thesis is to discuss IoT technologies and elaborate on how they are implemented in manufacturing processes. One empirical case study on IoT applications in shop floors and production lines carried out. Two cases were selected based on being a pioneer in implementing IoT technologies into manufacturing and highly optimized production at targeted factories. The cases represent next generation of smart factories which IoT technologies and in particular RFID solutions play an important role. A qualitative document analysis was conducted. The topic of this research is relatively new and therefore majority of references used for this paper are from 2014 onwards. Data were collected from public, non-confidential information sources including press releases, newspapers, articles and journals. The research approach was primarily descriptive with the focus on differences between previous production optimization technologies and IoT applications in use today.

The results of thesis demonstrates that IoT technologies bring transparency, traceability, adaptability, scalability and flexibility to the system. Therefore, the adoption of IoT has quite a few potential benefits, including improvement in cost and risk reduction, operational processes and value creation. This research also shows that using IoT technologies for their benefits is not an easy task for enterprises. Companies face many challenges on the way including layout changes in the factory's shop floor, changes in the design of the products, security concerns and consumer privacy. Moreover, since the IoT is a recent development, different aspects of the IoT such as economical, managerial and industrial aspects need to be studied. And this makes companies hesitant to make decisions regarding the adoption of IoT.

PREFACE

For the past four years I have been living in Finland and I feel I have grown more than ever. I have matured and now I see life differently. I am extremely grateful for this opportunity I had. Now it is time to move forward since the future is bright.

Being an Internet of Things enthusiast, I believe I couldn't have a better topic for my thesis. IoT is an interesting concept in its infancy stage with enormous potential. Therefore, writing my thesis was a pleasant process and I look forward to enjoy the fruits of this hard work later in my career.

I should thank a few people that without them I couldn't have done this research. First, I should thank my supervisor Professor Miia Martinsuo for her valuable and constructive feedback during the whole process. Second, I want to express my deepest gratitude towards my lovely parents, Mehri and Naser, who have always supported me all my life and I owe them big time! Finally, I want to thank my beautiful girlfriend, Pauliina, for always giving me positive energy and being there for me at hard times.

Tampere, April 2016

Paya Ghashghaee

CONTENTS

LIST OF SYMBOLS AND ABBREVIATIONS

AGV	Automated Guided Vehicle
B2B	Business to Business
B2C	Business to Consumer
BT	Bluetooth Technology
ERP	Enterprise Resource Planning
EWA	Electronic Works Amberg
GPS	Global Positioning System
HMI	Human-Machine Interfaces
IaaS	Infrastructure as a Service
IEEE	Institute of Electrical and Electronics Engineers
IT	Information Technology
IoE	Internet of Everything
IoT	Internet of Things
MES	Manufacturing Execution Systems
MT	Manufacturing Technology
PaaS	Platform as a Service
PLC	Programmable Logic Controller
PLM	Product Lifecycle Management
RFID	Radio Frequency Identification
SaaS	Software as a Service
TIA	Totally Integrated Automation
UHF	Ultra High Frequency
UM	Ubiquitous Manufacturing
UT	Ubiquitous Technology
VCC	Volvo Cars Corporation
VPC	Virtual Private Cloud
WIP	Work In Process
WSN	Wireless Sensor Networks

1. INTRODUCTION

1.1 Background

The Internet has become an essential global communication network among people. It supports communication between various devices. During past few years, Internet has extended its reach to connect things, such as heart beat monitors, temperature meters among many others to improve quality of life for people. It is safe to say that the long term goal of the Internet is to integrate human, things, data and different processes to create a powerful network and to do so, the Internet of Things (IoT) has been introduced to expand Internet connectivity to things. (Mashal et al., 2015)

Recently, IoT has gained massive attention all around the world. The IoT portrays objects that are capable of communicating through the Internet. Historically, the IoT referred primarily to Radio Frequency Identification (RFID) tagged objects that used the Internet to communicate. Nowadays, the IoT technology is used in many areas such as production optimization, supply chain management, retail tracking, stock control, efficient transportation, home automation, warehouse management, healthcare and many more. (Gao & Bai, 2014) In an IoT environment, things are not only connected to each other, but also required to be identified, located and managed. This means that each IoT object must have a name and an address and this make it harder to agree on a unique IoT architecture. (Mashal et al., 2015)

Most important aspects of IoT are RFID, (wireless) sensor networks and middleware. In case of IoT, a very crucial role is played by RFID systems, consists of readers and several tags. These technologies are used in automatic identification of any objects that the tags are attached to. They also help objects to be assigned with unique digital identities and to be integrated into a network. Another important part of IoT environments is sensor network. They collaborate with RFID systems to improve the tracking of things, collecting information about the position, movement and other necessary data. Generally, components of sensor networks are high number of sensing nodes, communicating in a wireless multi-hop way. Middleware job is the abstraction of the functionalities and communication features of the devices. Middleware plays an essential role between the things and the application layer due to limited storage and processing capabilities of objects and numerous types of applications involved. (Botta et al., 2016)

According to Anderson et al. (2015), IoT technologies cover various application areas at the moment such as security (e.g. access control, security care for elderly, time reporting for home care), payment (mobile payments), tracking and tracing (e.g. fleet management, logistics for goods transportation), health (e.g. e-home care), metering (e.g. smart power grids) and remote control and maintenance (e.g. smart homes, environmental monitoring). These areas can be divided into different application domains. In this research, the domains are categorized at personal and home, enterprise, utilities and mobile.

One specific application of IoT technologies is in smart manufacturing. According to Yoon et al. (2012), a smart factory uses ubiquitous computing technology to solve existing problems on the shop floor with existing components. Therefore in a smart factory, production happens through collecting, exchanging and using information anywhere anytime with sustainable network interaction among man, machine, materials and systems based on manufacturing technology. And with smart factory comes smart objects. Every piece of equipment have a certain degree of built-in intelligence. RFID is a pioneer to add intelligence to objects in a way that a low-power and low-cost processor is equipped with a memory and a wireless communication interface is attached to every component. (Zuehlke, 2010)

Manufacturing methods have changed dramatically along with the advancement of new technologies. At present, many manufacturing enterprises face common challenges which are timely, accurate and consistent inadequacies of manufacturing things during manufacturing execution. And therefore having access to real-time information helps decision makers to make smarter shop-floor decisions. (Zhang et al., 2015) Real-time data is required in production shop floors of manufacturing firms. New advancement in wireless technologies and ubiquitous computing technologies have brought up the term ‘Ubiquitous Manufacturing’ (UM) system. (Luo et al., 2015)

Using Internet of Things technologies results in generating more data. This data needs to be stored and processed. Therefore, manufacturers will be forced to define and implement new set of standards in order to coordinate and make the devices work together. As it is mentioned, even though IoT provides many new opportunities to the industry and end users in various applications, it lacks theory, technology architecture and standards. The key challenges of IoT are: architecture challenge, technical challenge, hardware challenge, privacy and security challenge, standard challenge and business challenge. (Chen et al., 2014)

According to Gartner (2014), by 2020, number of IoT objects will reach 26 billion units, up from 0.9 billion in 2009. This will have a significant effect on supply chain operations due to the available information. Moreover, IoT will impact many business processes including production line, retail delivery and store shelving by offering more accurate information and real-time visibility of the flow of materials and products. And most importantly, companies will invest in the IoT to reshape factory workflows, enhance tracking of materials and optimize distribution costs.

1.2 Objectives of the study

Since the concept of internet of things is relatively new, not many studies have been conducted about IoT and what it adds to manufacturing processes. The main focus of this study is on process optimization enabled by IoT in Business-to-Business (B2B) context. It takes into consideration the disruptions created by IoT in different businesses and the applications of IoT in various industries. Moreover, this study highlights the impact of IoT on enterprises and challenges and issues on the way of using it. Hence the objective of this paper is…

> *…To elaborate on how IoT technologies, particularly RFID solutions, are implemented in manufacturing processes.*

The study provides answers to following questions:

1. *How can manufacturers use IoT technologies in optimizing their production process?*
2. *What are the benefits of using IoT technologies on shop floors for factories?*
3. *What are the challenges and issues of implementing IoT into existing businesses?*

This research has two goals. First, the purpose of theoretical part is to briefly discuss the history, definitions, challenges and different characteristics of IoT. Also it elaborates on smart factory, smart objects and most importantly the applications of IoT in manufacturing processes. Second, the purpose of case studies is to take a closer look at two of the most reliable and highly optimized factories in the world and analyze their production lines to realize how they use IoT in their facilities. The case analysis provides a deep understanding of the role of RFID in shop floors. Moreover, answering the above questions explains the challenges and benefits of implementing IoT technologies into production processes. The research offers practical recommendations for companies with plans to employ IoT technologies into their production processes. Finally, on the back of literature review and empirical case study, this paper suggests a framework for integrating RFID, Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP).

1.3 Research context

This research is primarily focused on business to business context. The data from the theoretical study is gathered from most credible articles in the field of IoT. Most of the articles and scientific papers used in this section are published from 2014 onwards which is one of the positive points in this paper. The data for the case studies is collected from press releases, companies’ websites and credible journals.

The research strategy to find the right answers to the questions of the thesis was extensive literature research. All press releases of both case companies involved have been monitored since the implementation of IoT at their plants. Moreover, factories' suppliers which had an effective role in their manufacturing processes and ultimately in case studies have been studies in order to capture the necessary data.

1.4 Structure of the thesis

This Master of Science thesis is divided into six different chapters. The structure of the paper can be seen in Figure 1. Chapter 1 includes an introduction to the research, its structure, along with its main objectives. In the objective part three key questions has been asked and they are answered at the end of this study. Chapter 2 is the theoretical framework. It starts with IoT definition gathered from various articles and journals. Additionally, IoT technologies such as RFID and wireless networks are discussed in detail. One important part of chapter 2 is IoT applications. The focus of this section is on IoT applications in production optimization. Other applications of IoT in different industries for instance home automation, healthcare automotive industry are briefly discussed. The last two sections of chapter 2 are about the future of IoT and the opportunities and concerns that come along with it. It is based on statistics and various reports, future trends and technology developments related to IoT are reviewed.

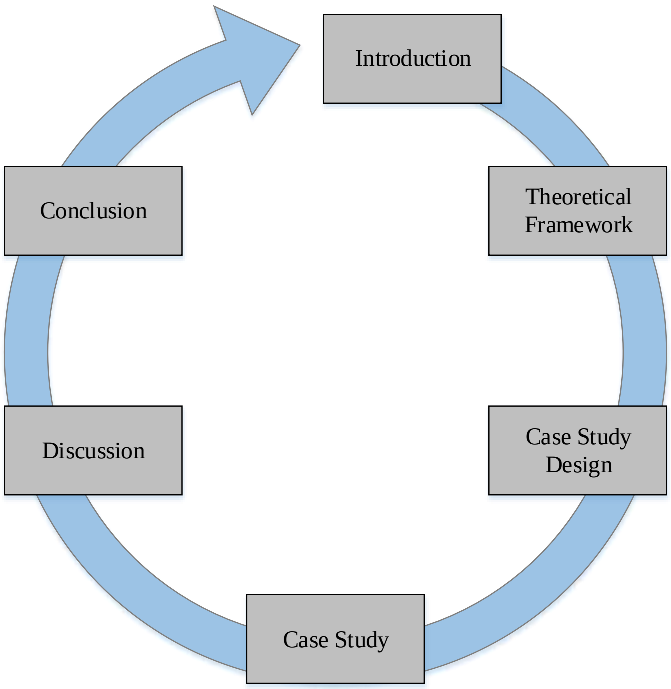

Figure 1. *Structure of the thesis*

Chapter 3 represents the case study design for the study. First, case selection justification is explained. Then, a short introduction of the case companies clarifies the reasons for this selections. The second part of chapter 3 presents a research approach including an overview of used data collection and analysis procedures. Chapter 4 in particular is an important part of this research. Both case studies are deliberately analyzed in this chapter. It starts with introducing the facilities and provided necessary information about them. Then, it continues with implication of IoT technologies inside the factories, the application of IoT and how it has been integrated inside those plants. And at the end of chapter 4 challenges of deploying IoT technologies into production lines and the opportunities it offers to companies are studied. In chapter 5, the questions asked in chapter 1 are answered thoroughly. The answers are given based the analysis of case studies. Also a framework for integration of RFID technologies, Manufacturing Execution Systems (MES) and Enterprise Resource Planning (ERP) is suggested. And finally, in chapter 6, a summary of existing literature is provided. Also, reliability, validity and limitations of the study are explained. In the last section, a few recommendations for companies' consideration and a few topics for further studies are suggested.

2. THEORETICAL FOUNDATION

2.1 Internet of things

2.1.1 Definition and features of IoT

In this chapter, various definitions and features of IoT are explained. Then, different IoT technologies are discussed in order to understand the role of IoT in its numerous applications. Next, smart factories, real-time data in ubiquitous manufacturing and challenges of applying RFID technologies in manufacturing, as key characteristics of process optimization, are discussed deliberately. During past 40 years, the Internet has been used mainly to connect people to each other through email, forums and most recently by social networking sites (SNS). However in the future, the Internet will serve as a link between devices, machines and other things through wired and wireless networks using an open standard Internet protocol (IP). (Dutton, 2014) The next movement in the era of computing is estimated to be outside the world of desktop. A new paradigm called Internet of Things has grown fast during past few years. (Botta et al., 2016) The term IoT was first pointed out by a British technology pioneer Kevin Ashton in 1999. (Ashton, 2009) As Andersson et al. (2015) explain, IoT is supposed to portray a major change in the history of the Internet as connections move beyond computing devices and start to connect billions of everyday devices from parking meters to home thermostats. According to Bogue (2014), Cisco Technology claims that the born of IoT was between 2008 and 2009 which the number of connected devices exceeded the world population. (Figure 2)

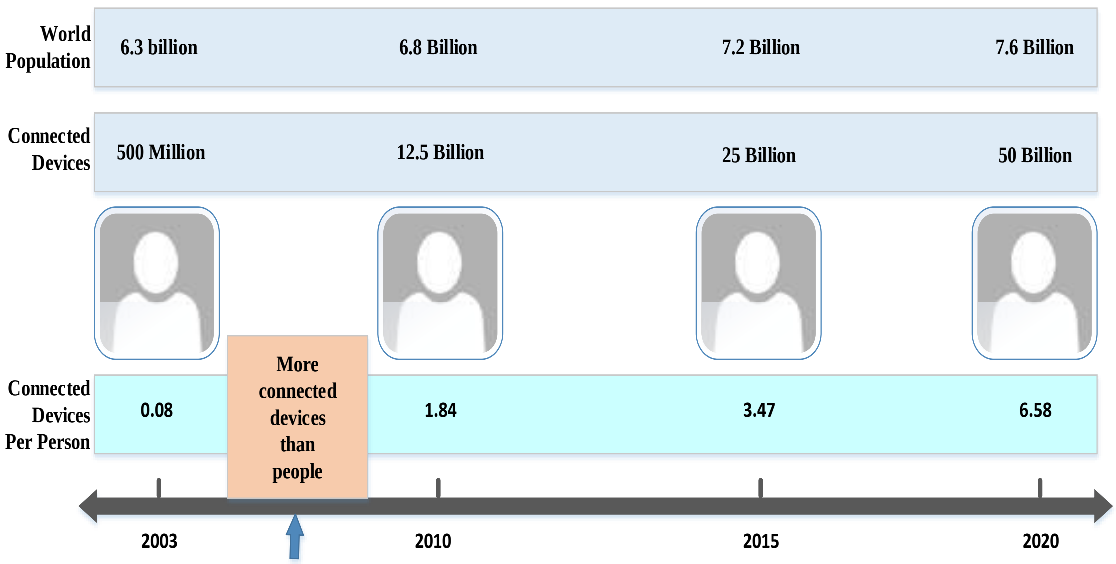

Figure 2. *Birth of the IoT (Adopted from Bogue, 2014)*

According to Cisco, there were 8.7 billion connected objects worldwide in 2012 and this number exceeded 10 billion in 2013, showing a rapid growth. It is predicted that the number of connected objects reaches 25 billion by 2015 and 50 billion by 2020. (Bogue, 2014)

The goal of IoT is to extend the benefits of the regular internet to physical objects by offering features such as constant connectivity, remote control ability and data sharing. (Gao & Bai, 2014) It promises one of the most disruptive technologies, enabling ubiquitous and widespread computing cases. IoT is all about the pervasive presence around people of things with ability to measure, understand and modify the environment. (Botta et al., 2016)

After reading quite a few articles and papers about IoT, its definition, applications, implementation challenges and future it becomes apparent that there is no exact and agreeable definition for IoT till now. Fernandez (2015) in his paper explains that even when companies invest in possibilities created by IoT they are still facing challenges to define its parameters and the concept of IoT has not yet been set in stone. Also Rong et al. (2014) believe that there is still no standard definition for IoT. Therefore in this research various definitions of IoT has been studied and gathered which can be seen in Table 1 below.

Table 1. *Definitions of IoT*

Author	Definition
Tan & Wang (2010)	Things having identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environmental and user contexts
Casagras (2011)	A global network infrastructure, linking physical and virtual objects through the exploitation of data capture and communication capabilities. This infrastructure includes existing and evolving Internet and network developments. It will offer specific object-identification, sensor and connection capability as the basis for the development of independent cooperative services and autonomous data capture, event transfer, network connectivity and interoperability.
Rainie & Wellman (2012)	IoT describes human-computer interaction that goes beyond personal computing to an environment of objects processing information and networking with each other and humans. Objects would share and learn information and preferred methods of use by gathering data about people who are in their environment.
Valery (2012)	The IoT consists of the protocols and related technologies that enable these many different devices to communicate over electronic communication channels, wired or wireless – a network of things, including people, that some have called the “thingternet”.
Gubbi et al. (2013)	Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with cloud computing as the unifying framework.
Vermesan et al. (2013)	IoT is a concept and a paradigm that considers pervasive presence in the environment of a variety of things/objects that through wireless and wired connections and unique addressing schemes are able to interact with each other and cooperate with other things/objects to create new applications/services and reach common goals.
IoT European Research Cluster (IERC) (2014)	A dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual “things” have identities, physical attributes, personalities and use intelligent interfaces and are seamlessly integrated into the information network.

As Table 1 represents, these definitions have many similarities and few differences which means some define IoT as a narrower concept and some definitions are broad. The definition chosen for this study belongs to Gubbi et al (2013). Their definition is well-rounded, acquainted and exactly points out at the topics covered in this paper. According to Dutton (2014) IoT is an umbrella term that includes various developments such as sensor networks and machine-to-machine (M2M) communications and some experts have argued to use more explicit terminology instead of IoT which is the main reason in the difference between IoT definitions.

2.1.2 IoT technologies

Our life will change by having lots of things connected and similar to the Internet changing the world, IoT technologies have that potential too. IoT technologies have been received large amount of attention and have variety of applications in many fields. (Schlick et al., 2013) The IoT represents objects that have the ability to communicate via the Internet. Therefore historically IoT is associated with RFID tagged objects that used the Internet to communicate. Nowadays IoT technology is used in different fields, for instance supply chain management, retail tracking, stock control, efficient transportation, households, warehouse management and healthcare. (Gao & Bai, 2014) There is no doubt that IoT technology will increase efficiencies across many industries which brings great benefits to consumers. (Uckelmann et al., 2011)

In order to understand the role of IoT in its numerous applications, IoT technologies should be first studied. Lee & Lee (2015) name five different IoT technologies. They describe them as widely used IoT technologies for the deployment of successful IoT-based products and services. Those five technologies are:

1. Radio frequency identification
2. Wireless sensor networks (WSN)
3. Middleware
4. Cloud computing
5. IoT application software

In IoT scheme, RFID systems play an important role. They are composed of one or more readers and several tags. These technologies support automatic identification of anything they are attached to by readers generating an applicable signal which triggers the tag transmission. In this way they let objects assigned to unique digital identities and to be integrated into a network and associated with digital information and services. (Kosmatos et al., 2011) RFID allows automatic identification and data capture by using radio waves. Interestingly the tag is able to store more data than traditional barcodes. It contains data in the form of the Electronic Product Code (EPC) which is a global RFID-based item identification system. For this interaction three types of tags are used: passive RFID tags, active RFID tags and semi-passive RFID tags. Passive RFID tags are not battery-powered. They get their power from the radio frequency energy transferred from the reader to the tag and they are mostly used in supply chains, passports, electronic tolls and item-level tracking. However active RFID tags have their own battery supply and since they have external sensors they are able to monitor temperature, pressure, chemicals and many other elements. Active RFID tags are used in hospital laboratories, manufacturing and remote-sensing Information Technology (IT) asset management. Finally the last type of tags are semi-passive RFID tags which communicate by drawing power from the reader and uses batteries to power the microchip. (Lee & Lee, 2015)

Wireless sensor networks is another essential technology in IoT environment. Sensor networks are generally consist of a potentially high number of sensing nodes[1], communicating in a wireless multi-hop[2] fashion. (Botta et al., 2016) These nodes typically have restrained resources, for example limited battery power, processing power and memory storage. WSN can cooperate with RFID systems to better monitor physical or environmental conditions. (Pesovic et al., 2010) Latest technological advances in wireless communications have made miniature devices available which are efficient, low-cost and low-power and are ready to be used in WSN applications. (Gubbi et al., 2013) WSN have mostly been employed in cold chain logistics that use thermal and refrigerated packaging methods to transport temperature-sensitive products. Moreover WSN are employed for maintenance and tracking systems. For instance, General Electric (GE) uses sensors in its jet engines, turbines and wind farms and GE saves valuable time and money through preventive maintenance by analyzing data in real time. (Lee & Lee, 2015)

Issarny et al. (2007) define Middleware as "a software layer that stands between the networked operating system and the application and provides well known reusable solutions to frequently encountered problems like heterogeneity, interoperability, security and dependability". Middleware is a software layer interposed between software applications. In other words middleware is a mechanism which connects all the components together and makes communication smoother and input/output interactions easier for software developers. It is an interface which simplifies the interaction between the 'Internet' and the 'Things'. Middleware got popular in 1980s because of its considerable role in facilitating the integration of legacy technologies into new ones. Moreover it simplified the development of new services in the distributed computing environment. (Lee & Lee, 2015) According to Kosmatos et al. (2011) the main job of middleware is the abstraction of the functionalities and communication capabilities of the devices. This task has its own challenges which are heterogeneity of the participating objects, their limited storage and processing abilities and vast variety of applications involved. Kosmatos et al. (2011) suggest

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[1] A connection point, a redistribution point or a communication endpoint (e.g. data terminal equipment)
[2] The type of communication which a node uses other nodes as relays to cover larger area is known as multi-hop routing in wireless mesh networks.

a middleware as a software layer which is consists of three sub-layers: Objects Abstraction, Service Management and Service Composition. (See Figure 3) These sub-layers mediate between the technological and the application levels according to interacting components/modules and abstracting resource and network functions.

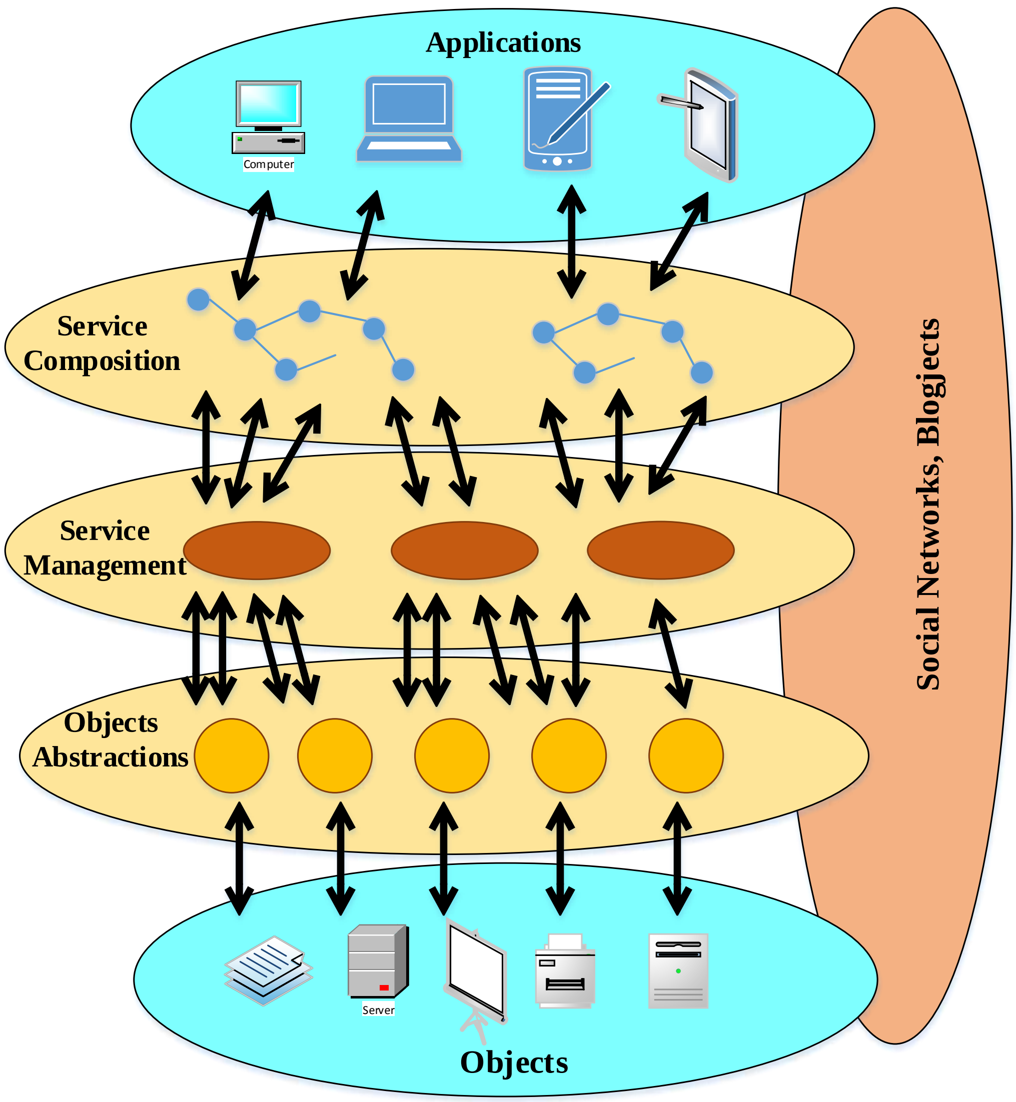

Figure 3. *IoT middleware architecture (Kosmatos et al., 2011)*

As it can be seen in Figure 3, the first layer is objects abstraction. What this layer does is translation of the services available to a set of device specific commands and vice versa by following a well-defined notification model. Due to objects abstraction layer the real world objects provide their abilities to the upper layers which results in enabling efficient service management and creation. Service management layer offers a basic but yet extensible set of functions for the connected objects such as dynamic object discovery, status monitoring, service configuration and mapping of available services for objects. The third layer is service composition which offers the corresponding functionality needed for the composition of plain or more sophisticated services by joining and combining services exposed by the service management layer. Finally, even though Application layer on top is not considered a part of middleware but it exploits all the functionalities provided by middleware architecture. (Kosmatos et al., 2011)

The term Cloud computing started to gain attention after the CEO of Google used it to describe the business model of providing services across the Internet in 2006, even though the term was not new. (Botta et al., 2016) Cloud computing has been defined by the National Institute of Standard and Technologies (NIST) as “a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction”. Cloud computing is a disruptive technology with profound implications for the delivery of Internet services in addition to entire IT sector. The acknowledgment of a new computing model got enabled by the availability of virtually unlimited storage and processing capabilities at low cost. In this case virtualized resources can be leased in an on-demand network access, being administered as general utilities. Giant companies such as Google, Microsoft and Amazon by adopting this paradigm for delivering services over the Internet have gained technical and economic benefits. (Botta et al., 2016)

After defining cloud computing, various aspects of cloud should be studied. To better understand the term cloud, different types of cloud, its layered architecture and service models are discussed in this research. There are many concerns for users to move an enterprise application to the cloud environment. These specific issues are mostly related to security (e.g. network security, data security and integrity), privacy (e.g. data confidentiality) and in some scenarios service providers are particularly interested in lower operation cost or high reliability. Therefore, there are different types of clouds, each with its own advantages and disadvantages (Zhang et al., 2010) as described below:

Public clouds: A cloud that offers its resources as services to the general public. The benefits of public clouds for service providers are no initial capital investment on infrastructure and shifting the risks to infrastructure providers. On the other hand, public clouds pose lack of control over network, data and security settings which hinders their effectiveness in many businesses.

Private clouds: Also known as internal clouds are provisioned for exclusive use by a single organization and they are generally owned, managed and operated by the same organization. Private clouds always offer maximum control over performance, reliability and security. On the down side, their disadvantages are their similarity to traditional proprietary server farms[3] and not being able to provide benefits such as lack of up-front capital costs.

[3] A server farm is a group of computers servers that provides server functionality far beyond the capability of a single machine and housed together in a single location.

Hybrid clouds: A hybrid cloud is composed of two or more cloud models (mostly public and private cloud models) which attempts to cover the limitations of each model. Hybrid cloud offers the versatility to run one part of the service infrastructure in private clouds and the other part in public clouds. Therefore they provide more flexibility than both public and private clouds in addition to higher control and security over application data compared to public clouds. However, for designing a hybrid cloud, public and private cloud components must be divided carefully.

Virtual Private Cloud (VPC): VPC is a platform running on top of public clouds and it is an alternative solution to address the constraints of private and public clouds. The biggest difference is that a VPC takes advantage of virtual private network (VPN) technology that enables service providers to setup their required topology and security settings (e.g. firewall rules). VPC virtualizes servers, applications and also the underlying communication network. Therefore, it basically is a more comprehensive design.

Typically, the architecture of a cloud computing environment consists of four layers: the hardware (datacenter) layer, the infrastructure layer, the platform layer and the application layer as it can be seen in Figure 3. The architecture of cloud computing is more modular than traditional service hosting environments like server farms. Each layer connects loosely with its upper and lower layers, granting each layer to evolve separately. This architectural modularity allows cloud computing to support various application requirements while lowering management and maintenance overhead. (Zhang et al., 2010)

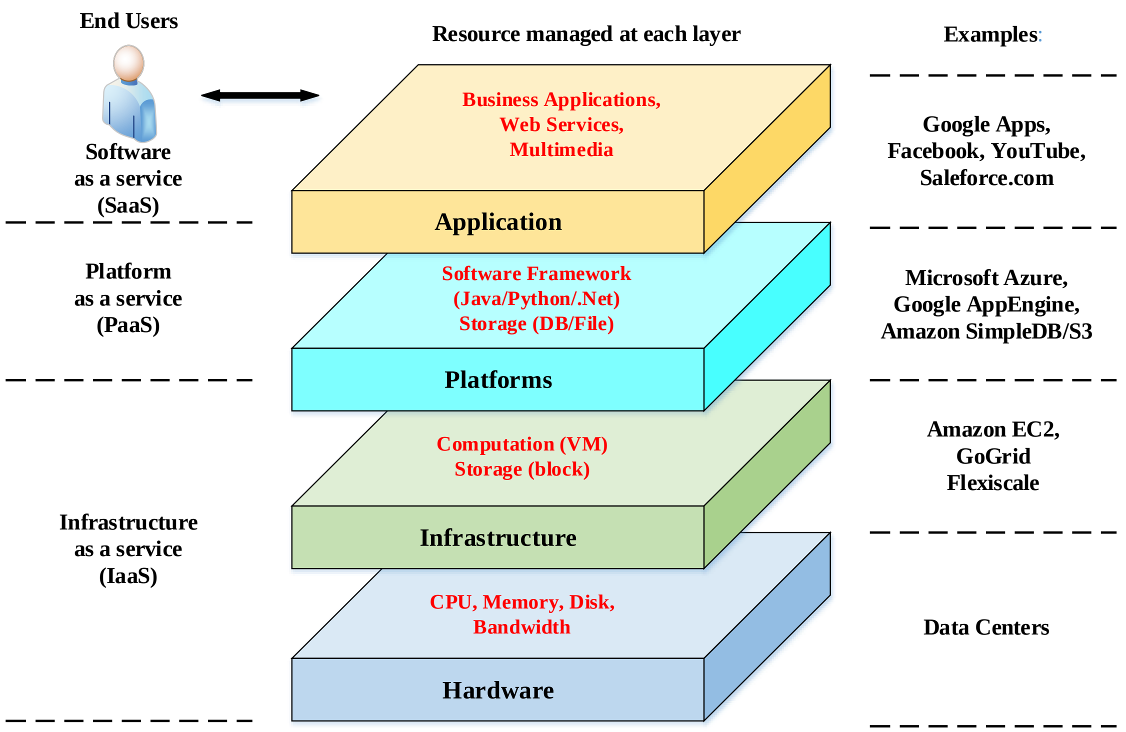

Figure 4. *Cloud computing architecture. (Zhang et al., 2010)*

As Zhang et al. (2010) describe each layer in detail, the responsibility of *hardware layer* is managing the physical resources of the cloud, such as physical servers, cooling systems, routers, switches and power. A data center typically includes thousands of servers that are organized and interconnected by switches, routers and other fabrics and hardware layer is usually implemented in data centers. The most common issues at hardware layer are hardware configuration, power and cooling resource management, fault tolerance and traffic management.

The infrastructure layer (virtualization layer) is responsible for creating a pool of storage and computing resources by using virtualization[4] technologies to partition the physical resources. The infrastructure layer has an important role in the architecture of cloud computing, because several key features such as dynamic resource assignment, are accessible duo to virtualization technologies.

The platform layer is the layer which contains operating systems and application frameworks. The platform layer is responsible for minimizing the concern of deploying applications directly to virtual machine containers.

And finally the *application layer* which is built on top of the platform layer contains the actual cloud applications. The difference between cloud applications and traditional applications is that cloud applications benefit from the automatic-scaling feature to gain better performance, lower operating cost and availability.

Cloud computing utilizes a service-driven business model shown in Figure 5. Put differently, cloud computing hardware and platform level resources can be reached as services on an on-demand basis.

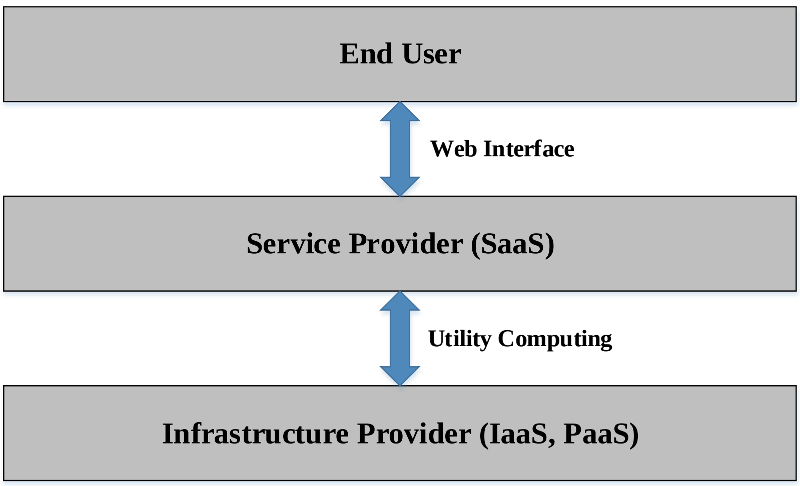

Figure 5. *Cloud computing business model. (Adopted from Zhang et al, 2010)*

[4] Virtualization is a combination of software and hardware engineering that creates Virtual Machines (VMs). It is an abstraction of the computer hardware that allows a single machine to act as if it where several machines. (Intel.com)

Theoretically, each layer explained above can be considered as a service to the layer above and as a customer of the layer below. However, in practice, clouds offer services which can be divided into three categories of *Infrastructure as a Service* (IaaS), *Platform as a Service* (PaaS) and *Software as a Service* (SaaS). According to NIST, IaaS provides processing, storage and network resources capabilities and allows consumers to control the operating system, storage and applications. For instance, GoGrid, Amazon EC2 and Flexiscale are among IaaS providers. PaaS Refers to providing platform layer resources, including software development framework and operating system support. Examples of PaaS providers can be Force.com, Google App Engine and Microsft Windows Azure. And finally SaaS refers to provisioning of on-demand applications over the Internet. A few examples of SaaS providers are SAP Business ByDesign, Rackspace and Salesforce.com. (Zhang et al., 2010) All the cloud services, their examples and their placement in cloud architecture can be seen in Figure 3.

While devices and networks provision physical connectivity, IoT applications enable machine-to-machine and human-to-machine interactions in a reliable and sturdy manner. The responsibility of IoT applications on devices is to make sure that data or messages have been received, processed and acted upon accordingly and on time schedule. For instance, transportation and logistics applications continually monitor the status (e.g. temperature, shock, humidity) of transported goods such as meat, fruits and dairy products and necessary actions are taken automatically to prevent spoilage. A good example for this procedure is FedEx. FedEx acquired SenceAware[5] to be able to check the location, temperature and other elements of a package both during delivery and after the package is opened. It is crucial for IoT applications to be intelligently built thus devices will be able to monitor the environment, identify problems, communicate among each other and solve problems without human interference. (Lee & Lee, 2015)

Lee & Lee (2015) believe that understanding the customer value of IoT applications for organizations is the key to fruitful IoT adoption. Therefore, they classify three IoT categories for enterprise applications which are discussed below.

Monitoring and control: Monitoring and control systems generally gather data on energy usage, equipment performance and environmental conditions and enable managers and automated controllers to continuously track performance in real time anywhere, anytime. Utilizing advanced monitoring and control technologies (e.g. smart grid[6], smart metering[7]) makes it easier to find out operational patterns, spot areas of potential improvement, foresee future fallouts and optimize operations which results in lower costs and higher

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[5] SenceAware combines a powerful online application with a multi-sensor device to provide near real-time information about shipments. (senseaware.com)
[6] It is an evolved grid system that manages electricity demand in a sustainable, reliable and economic manner, built on advanced infrastructure and tuned to facilitate the integration of all involved. (new.abb.com)
[7] Smart meter is an electronic device that records consumption of electric energy and communicates that information back to the utility for monitoring and billing. (wikipedia.org)

productivity. (Lee & Lee, 2015) A good example for using monitoring and control technologies in business-to-business (B2B) world is in oil and gas industry. These technologies provide real time data from extraction and drilling equipment and related systems, transport systems and refineries to enterprise systems. Consequently the added value of utilizing these technologies are improved productivity, lowed accident frequency and reduced field inventories. (Harbor Research, 2013) Benefiting from IoT to monitor and control various components in cars is an illustration of IoT applications in business-to-consumer (B2C) context, developed to boost customer value. In 2014, Ford and Intel joined forces to personalize drivers' experience taking advantage of facial recognition software and a mobile phone app. The goal of the project is improving privacy controls and identifying different drivers and automatically adjust features according to an individual's preferences. Furthermore, the in-car experience is personalized by displaying information specific to each driver, for instance personal calendar, contacts or preferred music. (Lee & Lee, 2015)

Big data and business analytics: IoT devices with embedded sensors and actuators generate massive amounts of data and transmit it to business intelligence and analytics tools where decisions are made by humans. These data are utilized to solve business problems such as reducing product test times and market conditions. (Lee & Lee, 2015) According to Bughin et al. (2015) gathering data from multiple IoT systems will not be enough to create opportunities for companies. By using IoT for prediction and optimization, organizations face a new analytics challenge. The challenge is that companies have to develop or purchase, customize and deploy an analytical software that extracts valuable data from the stream of data generated by IoT. As an example, Intel does a meticulous quality check (involving a complex series of tests) over every chip they produce. Intel realized by using historical information gathered during manufacturing, the number of tests required can be diminished which resulted in lowered test time. This solution avoided test costs of $3 million in 2012 for one series of Intel Core processors. (Intel.com/iot) Moreover IoT-based big data are changing healthcare product industry. Proctor & Gamble has developed an interactive electric toothbrush called Oral-B Pro 5000 that provides users a smart and personalized oral care routine. The interactive electric toothbrush logs brushing habits with mobile technology while giving mouth-care tips and news headlines. (Lee & Lee, 2015)

Information sharing and collaboration: Information sharing and collaboration in the IoT can happen between things, between people and things and between people (shown in Figure 6) which increases situational awareness and avoids information delay and misrepresentation.

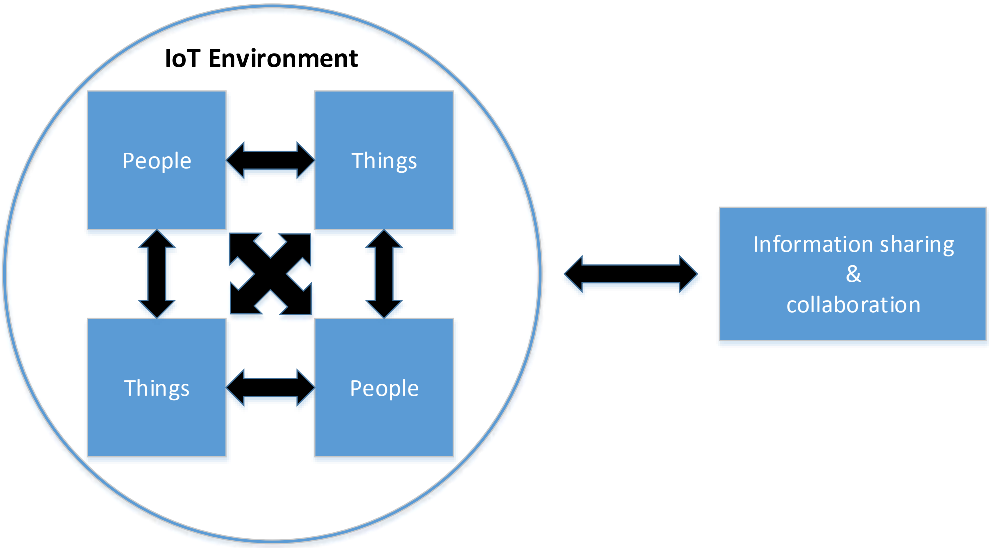

Figure 6. *Network processes for information sharing and collaboration*

As an example, in supply chain field, if sensors are placed all around a retail store where refrigeration is essential, a malfunction in one of the refrigerators leads to an alert sent to the store manager's mobile device. Then the manager checks employees' availability by reviewing their employee status report and send task assignment to an available employee through his or her IoT-enabled mobile device. (Lee & Lee, 2015) A real case of sharing information among different kinds of devices, successfully implemented, is Fujitsu's site 'Shimane'. Shimane Fujitsu manufactures notebook computers and tables. They developed a manufacturing system software that displays the status of different vendor's devices by developing four software. Firstly, a connection software for each device followed by creating the second software which enables all devices on a network to share information among each other. Thirdly, a software which converts various types of data into a common format in order to acquire information from each device. And finally, a software was needed to show status information for each device. In this way, production is optimized and supported by data sharing and manufacturing is based on full interaction between humans and machinery enabled by using IoT technologies such as RFID tags. (Nishioka, 2015)

2.1.3 IoT application domains

According to Anderson et al. (2015), IoT technologies cover various application areas at the moment such as security (e.g. access control, security care for elderly, time reporting for home care), payment (mobile payments), tracking and tracing (e.g. fleet management, logistics for goods transportation), health (e.g. e-home care), metering (e.g. smart power grids) and remote control and maintenance (e.g. smart homes, environmental monitoring). These areas can be divided into different application domains. Gubbi et al. (2013) categorize these applications into four application domains based on type of network availability, coverage, scale, heterogeneity, repeatability, user involvement and impact. They explain how each domain will be impacted by the emerging Internet of Things. The four domains are: (1) Personal and Home IoT at the scale of an individual or home, (2) Enterprise IoT at a community scale, (3) Utilities IoT at the scale of a region or nation and (4) Mobile IoT which is typically spread across other domains mostly because of the nature of connectivity and scale.

Personal and home: In this domain only the owner of the network can use the collected sensor information. Typically Wi-Fi is used as the primary element enabling higher bandwidth data (video) transfer as well as higher sampling rates (sound). During the past twenty years ubiquitous healthcare has been envisaged. Today, IoT provides an impeccable platform to realize this vision by benefiting from body area sensors to upload the data to servers. As an example, a smartphone equipped with Bluetooth technology (BT) can be used for communication with interfacing sensors measuring physiological parameters. Currently, there are many applications available for Google Android, Apple iOS and Windows Phone operating systems that measure different parameters. (Gubbi et al., 2013) Within a home, many appliances could be brought into IoT because of cost saving reasons. Home thermostats and hot water heaters are good examples, because they can be monitored and controlled remotely. Another example is adding sensors to security systems, parking doors and stovetop, for more ease of mind and to relieve security concerns. The same logic can be implemented into third-party systems. This creates an interactive home which is able to give recommendations about its own upkeep and no direct input from the homeowner is needed to make decisions. (Fernandez, 2015)

Enterprise: An enterprise based application is defined as the ‘Network of Things’ within a work environment. Typically, the information collected from these networks can only be accessed by the owners and the data may be released selectively. Regarding factory maintenance, sensors have always been an integrated component of a factory setup involved in various areas such as security, climate control and automation. Eventually, this will be replaced by a wireless system which provides the flexibility to make changes to the factory setup whenever it is necessary. And it can be called an IoT subnet dedicated to factory maintenance. (Gubbi et al., 2013) Moreover, Smart Environment as another major IoT application is growing fast. Mark Weiser as a pioneer defined a smart environment as “the physical world that is richly and invisibly interwoven with sensors, actuators, displays and computational elements, embedded seamlessly in the everyday objects of our lives and connected through a continuous network”. (Weiser & Gold, 1999; cited in Gubbi et al., 2013) Smart environment as an IoT application consists of several subsystems as it can be seen in Table 2.

Table 2. *Smart environment application domains.(Adopted from Gubbi et al., 2013)*

	Smart home	**Smart retail**	**Smart city**	**Smart agriculture/forest**	**Smart water**	**Smart transportation**
Network size	Small	Small	Medium	Medium/large	Large	Large
Users	Very few, family members	Few, community level	Many, policy makers, general public	Few, landowner, policy makers	Few, government	Large, general public
Internet connectivity	Wifi, 3G, 4G LTE	Wifi, 3G, 4G LTE	Wifi, 3G, 4G LTE	Wifi, satellite communication	Satellite communication, microwave links	Wifi, satellite communication
Data management	Local server	Local server	Shared server	Local server, shared server	Shared server	Shared server
IoT devices	RFID, WSN	RFID, WSN	RFID, WSN	WSN	Single sensors	RFID, WSN, single sensors

Table 2 also represents different characteristics of subsystems forming smart environment from technological point of view. Each of the sub domains usually cover many focus groups and the data will be shared among them. (Gubbi et al., 2013)

Utilities: The main characteristic of Utilities domain which separates it from the previous two is the fact that the information from the networks in utilities domain is often used for service optimization instead of consumer consumption. Many utility companies use the data (e.g. smart meter by electricity supply companies) for resource management and ultimately cost vs. profit optimization. Utility domain applications consist of broad networks laid out by large organizations in order to monitor critical utilities and efficient resource management. And usually the backbone network used can be cellular, Wi-Fi or satellite communication depending on the scale of the network. Smart grid and smart metering both fall into utilities IoT domain. Efficient energy consumption is possible through continuous monitoring of electricity points and applying this information to make the necessary changes in the way electricity is consumed. An example could be water network monitoring and quality assurance of drinking water that uses IoT. Sensors are installed at crucial locations to measure critical water parameters and make sure of high supply quality. This evades incidental contamination among storm water drains, drinking water and sewage disposal. (Gubbi et al., 2013)

Mobile: Smart logistics, urban traffic and smart transportation are all among mobile IoT domain due to the nature of data sharing and backbone implementation. Traffic congestion causes tremendous costs on economic and social activities in many cities. Generally, supply chain efficiencies and productivity, such as just-in-time operations are extremely impacted by this traffic jam, resulting in delivery schedule failures and freight delays. Therefore, dynamic traffic information might be a solution. It helps with freight movement, enables better planning and improved scheduling. The transport IoT will overtake the traffic information provided by the existing sensor networks by allowing the use of large scale WSNs for online monitoring of travel times, original-destination route choice behavior, queue lengths and air pollutant and noise emissions. Another important application in mobile IoT domain is the emergence of Bluetooth technology devices which shows the current IoT penetration in a number of digital products such as tablets, mobile phones and navigation systems. The signals sent by BT devices with a unique Media Access Identification (MAC-ID) number, can be read by BT sensors within the coverage area. Moreover, readers which are placed at various locations can be utilized to identify the movement of the devices. (Gubbi et al., 2013)

2.1.4 Future of IoT

Gartner (2014) predicts that IoT-enabled devices will reach 26 billion units by 2020 and it will impact investors and businesses of all types and consequently affects technologies that are being developed today. IoT will transform business processes from production line and warehousing to store shelving and retail delivery by offering more accurate information and real-time visibility into the flow of materials and products. By investing in IoT, companies will redesign the workflows of factories, optimize distribution costs and improve tracking of materials. For instance, companies such as John Deere and UPS are now using IoT-enabled fleet tracking technologies to cut costs and improve supply efficiency. (Lee & Lee, 2015) Internet of Things has been recognized as one of the emerging technologies in IT according to Gartner's IT Hype Cycle[8] (Appendix 1). It has been predicted that the market adoption of IoT will take 5 to 10 years. The popularity of various paradigms differ with time. As it is shown in Figure 7, the web search popularity of the term Internet of Things has risen dramatically during past 12 years.

[8] A Hype Cycle is a way to represent the emergence, adoption, maturity and impact on applications of specific technologies.

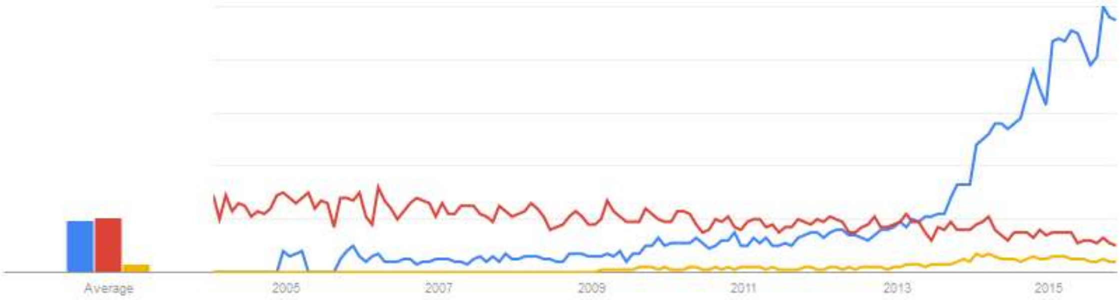

Figure 7. *Google search trends since 2004 for terms Internet of Things, Wireless Sensor Networks and Internet of Everything.*

As it can be seen, search volume of the term Internet of Things is constantly increasing, while the trend for Wireless Sensor Networks falling every year. Moreover, Internet of Everything (IoE) is another term compared to Internet of Things in Figure 6. Bradly et al., (2013) define IoE as “bringing together people, process, data and things to make networked connections more relevant and valuable than ever before – turning information into actions that create new capabilities, richer experiences and unprecedented economic opportunity for businesses, individuals and countries.” IoE has gained some attention since 2009 and it is still in infancy, but Cisco has forecasted that IoE will create $14.4 trillion in Value at Stake by increasing revenues and lowing costs among companies in different industries from 2013 to 2022.

Many firms including Microsoft, IBM, Intel and DHL are all investing in the IoT and predict gigantic future growth for IoT. For instance, Business Insider in one of its recent reports forecasts that the IoT will be the largest device market in the world by 2019, overtaking mobile devices and desktop computers combined and create $1.7 trillion in new value. (Fernandez, 2015) Today, different kinds of IoT applications have emerged, and the number of enterprises that are willing to utilize them is quickly increasing. Figure 8 represents a road map of the technology drivers and key application outcomes expected in the next ten years.

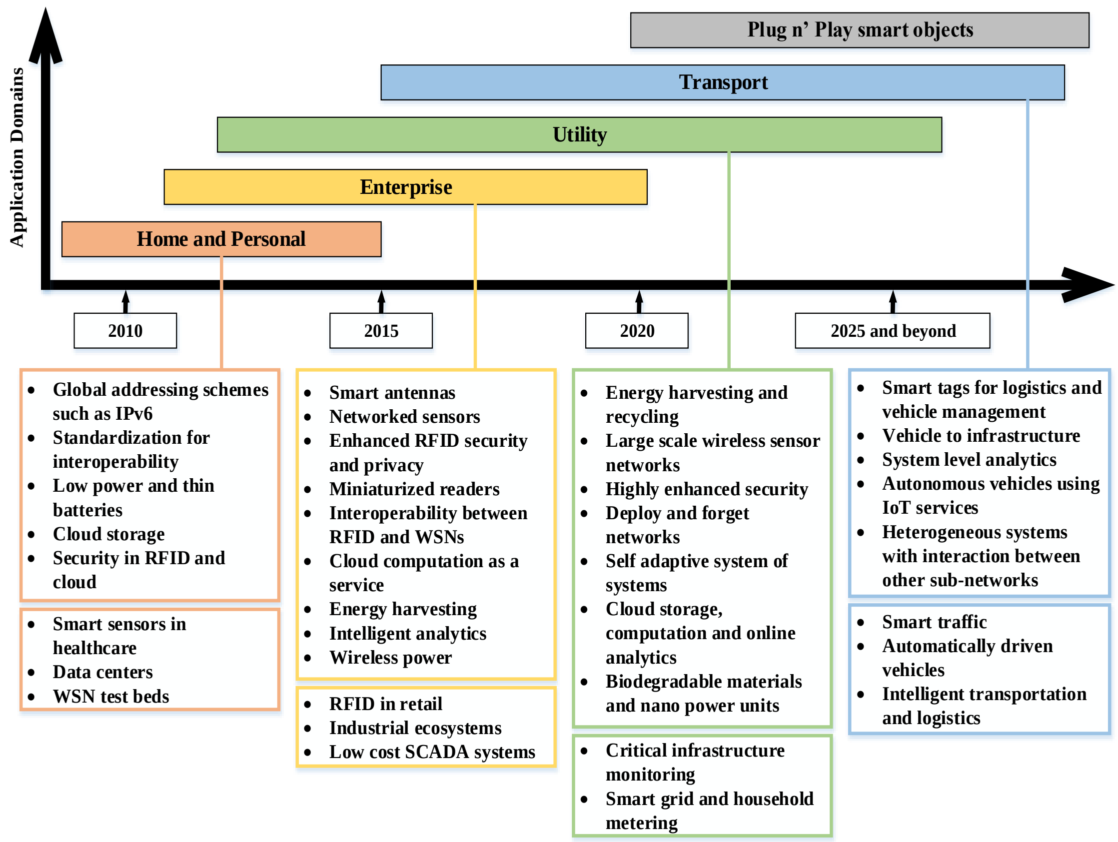

Figure 8. *Roadmap of key technological developments in the context of IoT application domains envisioned. (Adopted from Gubbi et al., 2013)*

As it can be seen in Figure 8, this roadmap features the key developments in IoT research in the context of pervasive applications. It shows four IoT application domains and also a domain called ‘Plug n` Play smart objects’ yet to be added to the other domains in the future. McKinsey predicts that the potential economic impact of the Internet of Things will be in range of $2.7 to $6.2 trillion per year by 2025. (Manyika et al., 2013) From an industry’s point of view, four industries compose more than half of the IoT in value. As Lee & Lee (2015) explain, these four dominant industries in terms of value at stake are manufacturing with 27%; retail trade with 11%; and information services and finance and insurance, both at 9%. In addition, other industries such as wholesale, healthcare and education all fall in the range of 1 to 7 percent, in terms of value generation. Manufacturers gain most of their value through higher agility and more flexibility in factories and also from the ability to use workers’ skills to the most. Meanwhile, much of the value for retailers comes from connected marketing and advertising.

2.1.5 Opportunities and concerns

The opportunities behind the IoT as the near future technology and in business is very positive in various areas but not possible to implement in practice. In many cases, it is feasible both technically and financially to use IoT technologies but there are some challenges on the way such as organizational, institutional and public policy constraints. It is promised that IoT will change the way we do things but organizations are changing slow due to complicated policy issues such as concerns towards data protection and privacy, ownership of data and standard setting between authorities. Therefore, till social and policy changes meet with technical opportunities, IoT developments will be slowed considerably. (Dutton, 2014)

IoT will create many opportunities for firms by enhancing data collection, enabling real-time responses, increasing efficiency and productivity, improving access and control of devices, and connecting technologies. Through IoT, frequent data collection will be possible, thus, today's big data will soon be tomorrow's little data. For instance, when a consumer wears a health-related IoT device, vital information (e.g. body temperature, pulse and distance traveled) can be collected continuously. Then, these data can be used to optimize outcomes for a person, such as weight loss and fitness. Another benefit of IoT is that, the data can be collected instantly which makes the real-time decision making happen and afterwards necessary actions will be taken. This would have a positive impact on supply chain management services. For instance, pay-as-you-go[9] could be expanded beyond car rentals and mobile phone services to insurance or any other application. Moreover, fixed pricing in many contexts such as vending machines or parking meters, would become dynamic. The next benefit of IoT is in enhancing productivity at a larger scale where coordination of numerous pieces is crucial. As an example different devices/appliances (e.g. locks, lighting, kitchen appliances and electric devices) in a house can be tied together and make a connected home. This would result in higher efficiency, effectiveness and satisfaction. (Weinberg et al., 2015) As an added benefit, IoT can provide greater access and control over Internet-connected devices. For example, General Electric's (GE) smart jet engines now are able to transmit over one terabyte of sensor data during every flight. Therefore, by being able to access to this data, the airline already knows if any maintenance is required before plane lands. (Kavis, 2014)

Porter & Heppelmann (2014) discuss that, completely new set of product functions and capabilities are enabled through intelligence and connectivity. They categorize the abilities enabled by IoT (or in general abilities of smart connected products) into four group as it is shown in Figure 9. These are groups are: (1) monitoring, (2) control, (3) optimization and (4) autonomy.

[9] A system of meeting costs as they arise or paying for a service before it is used.

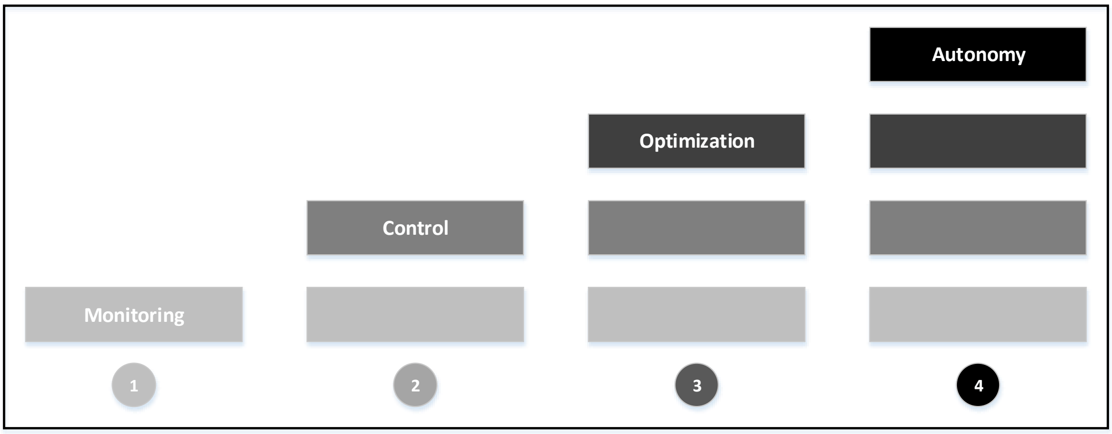

Figure 9. *Capabilities of smart connected products. (Adopted from Porter & Heppelmann, 2014)*

In monitoring, sensors and external data sources enable the thorough monitoring of product's operation and usage, product's condition and external environment. It also enables alerts and notifications of changes. The second group is control which happens through the software embedded in the product or in the product cloud. The software allows control of product functions and personalization of the user experience. The next group is optimization. The purpose of optimization is enhancing product performance and allowing predictive diagnostics, service and repair. To elaborate more, monitoring and control capabilities facilitate algorithms that optimize product operation and use. Autonomy is the last group in Figure 8. It is the combination of three previous groups. In other words, combining monitoring, control and optimization allows autonomous product operation, self-coordination of operation with other products and systems, autonomous product enhancement and personalization, and self-diagnosis and service. (Porter & Heppelmann, 2014)

Using Internet of Things technologies results in generating more data. This data needs to be stored and processed. According to Adshead (2014), the amount of data on the planet will grow from 4.4 zettabytes (10^{21} bytes) to 44 zettabytes and 10% of this amount will be created by IoT. This huge amount of data raises concerns about privacy, data processing, data ownership, communication and standards. Manufacturers will be forced to define and implement new set of standards in order to coordinate and make the devices to work together. Therefore, deploying different approaches such as data structures and communications, considering IoT is needed. (Weinberg et al., 2015)

Privacy issues regarding using IoT technologies are challenging to solve without facing other issues like trust. Guerra et al. (2003) explain a concept called "trust tension" tied to privacy noting 'data collection can help trust by creating a legal bond between the parties involved. However, the collection and availability of data can create problems of trust in terms of privacy since individuals may be wary of data surveillance or of the secondary use of that information. Indeed, privacy is repeatedly identified as a concern that prevents consumers from using the internet for transactions. In this way, there is a "trust tension" between privacy and identity. Absence of data impedes trust as accountability is limited, but data gathering creates trust problems regarding the use of the data and intrusions on privacy'. Therefore, in IoT, generating huge amount of data will create concerns over privacy, while the lack of data results in undermining trust. The big task for organizations using IoT is to come up with solutions to balance these tensions. Another uncertainty is about the ownership of the collected data by IoT in different scenarios that involve multiple actors. Typically, copyright agreements are signed to clarify the owner of the produced data by a machine. (Dutton, 2014) In case of an IoT object ownership, this object might be owned by a specific company, could be co-owned by several companies or it can be part of a public or private infrastructure. The concern then would be who has the authority to utilize the object and decide on how it is interacting with other IoT objects which requires modification in business model design. (Anderson et al., 2015) Cyber security is also a concern for the data or systems developed by IoT. The IoT cloud create very sensitive data as well as supporting safety critical systems, such as managing transportation, powering or human health monitoring. It is necessary that these systems be safe and secure from intrusion by an unauthorized user or any unintentional data breaches by authorized personnel to handle data. (Dutton, 2014)

In order to make the IoT more understandable, media normally focuses on consumer applications, however according to Bughin et al. (2015), 70 percent of the value created from IoT within next ten years is from B2B applications. The IoT uncovers opportunities for optimization, enhanced business processes, improved efficiency. It enables businesses to customize their product, to have access to real-time data and ultimately make wise decisions. Therefore, in next part of this chapter, smart factory, real-time data in ubiquitous manufacturing and challenges of applying RFID technologies in manufacturing are well discussed.

2.2 Optimizing manufacturing processes

2.2.1 Smart factory

According to Radziwon et al. (2014), the word 'smart' refers to an independent device, and the device normally includes a sensor, an actuator, a microcomputer and a transceiver. Moreover, 'smart' as an adjective is also used to explain an object that was improved by implementation of extra features, which enhance its computational and communication abilities. The term 'smart factory' has been used by both academics and industrial professionals but there is no exact definition. Usually scholars consider 'smart factory' as an approach, a technology or a paradigm and they use synonymous terms such as: U-Factory (ubiquitous factory), factory-of-things, intelligent factory of the future and real-time factory. According to Zuehlke (2010), embedded intelligence in all connected devices is a prerequisite for 'smart factory' while some of the essential functionalities are provided by RFID technology. He explains that, not only 'smart factories' have modular structure but also they are internally connected by a wireless network which means every device should have its own IP address.

Based on the research done by Radziwon et al. (2014), characteristics of 'smart factory' are being flexible and configurable, agile, lean and low cost. They mention applying modular structure with respect to both product/process technology and organization is one way to make those characteristics happen. Therefore they define 'smart factory' as: "*A manufacturing solution that provides such flexible and adaptive production processes that will solve problems arising on a production facility with dynamic and rapidly changing boundary conditions in a world of increasing complexity. This special solution could on the one hand be related to automation, understood as a combination of software, hardware and/or mechanics, which should lead to optimization of manufacturing resulting in reduction of unnecessary labor and waste of resource. On the other hand, it could be seen in a perspective of collaboration between different industrial and nonindustrial partners, where the smartness comes from forming a dynamic organization."* Wang et al. (2016) defines 'smart factory' as: "*a manufacturing cyber-physical system*[10] *that integrates the physical objects such as machines, conveyers and products with the information systems such as MES and ERP to implement the flexible and agile production.*" Wang believes the smart factory is an essential aspect of Industry 4.0 which offers networked manufacturing systems and the vertical integration for smart production. The combination of smart objects with the big data analytics is needed for implementation of smart factory. So that the smart object configurability leads to higher flexibility and feedback and coordination is offered by the big data analytics to accomplish better efficiency. In this way, the smart factory can manufacture customized and small-lot products efficiently and profitably. A framework for the smart factory of Industry 4.0 can be seen in Figure 10 below.

[10] CPSs are integrations of computation and physical processes. (Lee, 2008)

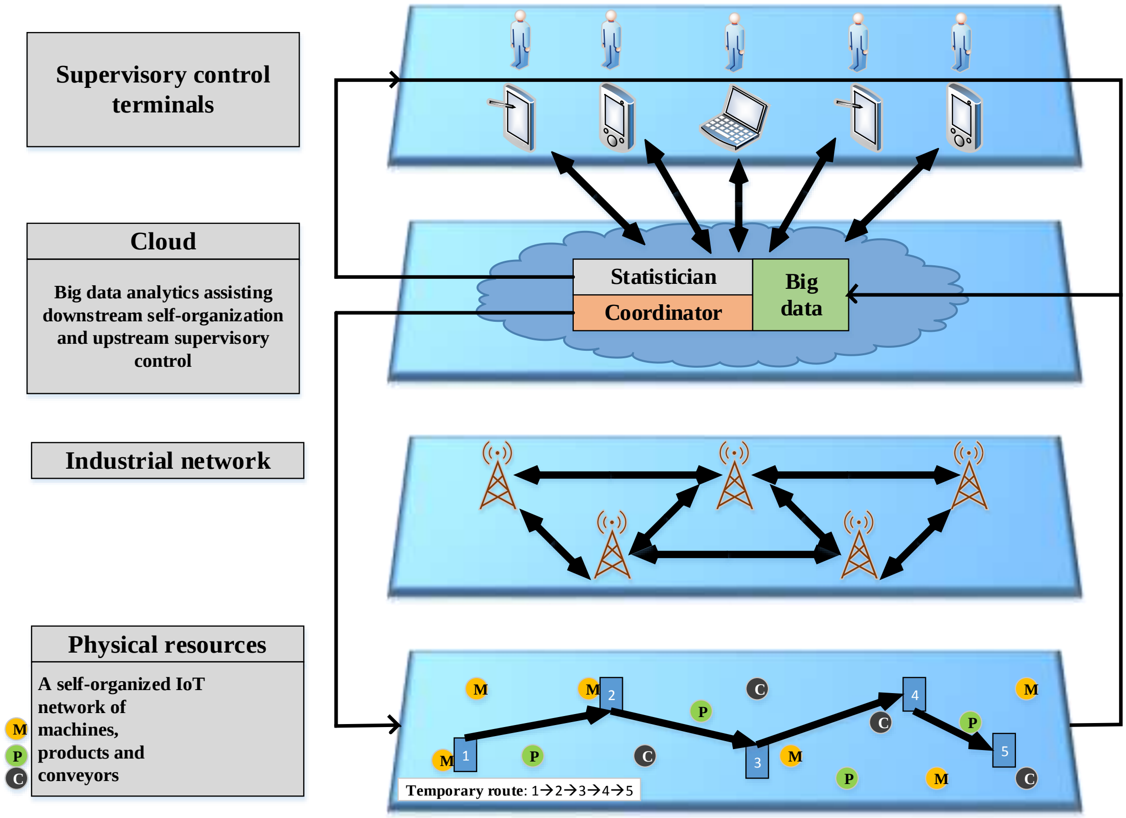

__Figure 10.__ Framework of the smart factory of Industry 4.0. (Adopted from Wang et al., 2016)

As it is shown in Figure 10, smart factory framework is created by four layers called: physical resource layer, industrial network layer, cloud layer and supervisory control terminal layer. These layers work in a way that physical resources as smart objects communicate among each other, using the industrial network. Then cloud collects significant amount of data from the physical resource layer and collaborate with people through supervisory control terminals. (Wang et al., 2016)

2.2.2 Real-time data in ubiquitous manufacturing

At present, many manufacturing enterprises face common challenges which are timely, accurate and consistent inadequacies of manufacturing things during manufacturing execution. And therefore having access to real-time information helps decision makers to make smarter shop-floor decisions. (Zhang et al., 2015) Real-time data is required in production shop floors of manufacturing firms. New advancement in wireless technologies and ubiquitous computing technologies have brought up the term 'Ubiquitous Manufacturing' (UM) system. (Luo et al., 2015) Sun et al. (2008), define UM system as a system established on wireless sensor network that assists the automatic collection and real-time processing of field data in manufacturing processes. They categorize the characteristics of UM as presented below:

1. It integrates manufacturing technology (MT), information technology and ubiquitous technology (UT)
2. It covers manufacturing-related activities throughout the whole product lifecycle
3. It transparently collects and employs every product-related data at individual level
4. It facilitates real-time collaboration between stakeholders in a distributed environment.

These characteristics create an opportunity to minimize the uncertainty and disturbance all through the production process and close the loop of production planning, scheduling and execution.

Regarding data collection, RFID technology offers a fast and accurate way to collect real-time data from shop floor. Therefore employing RFID technology in the production planning and control has significant benefits. For maximum optimization, there should be a consistent dual-way connection between decision-making level and execution level. RFID tags can be attached to production resources, for instance product component, pallets, machines and operators. They are flexible and practical data carriers which are used to transfer information. The production data collected from shop floor can be written and rewritten without any manual interference. And also in a dynamic production environment is it highly important that production resources are able to carry their own status information and interact with each other. (Luo et al., 2015) The roadmap of RFID-enabled ubiquitous manufacturing infrastructure consists of three core components as presented in Figure 11.

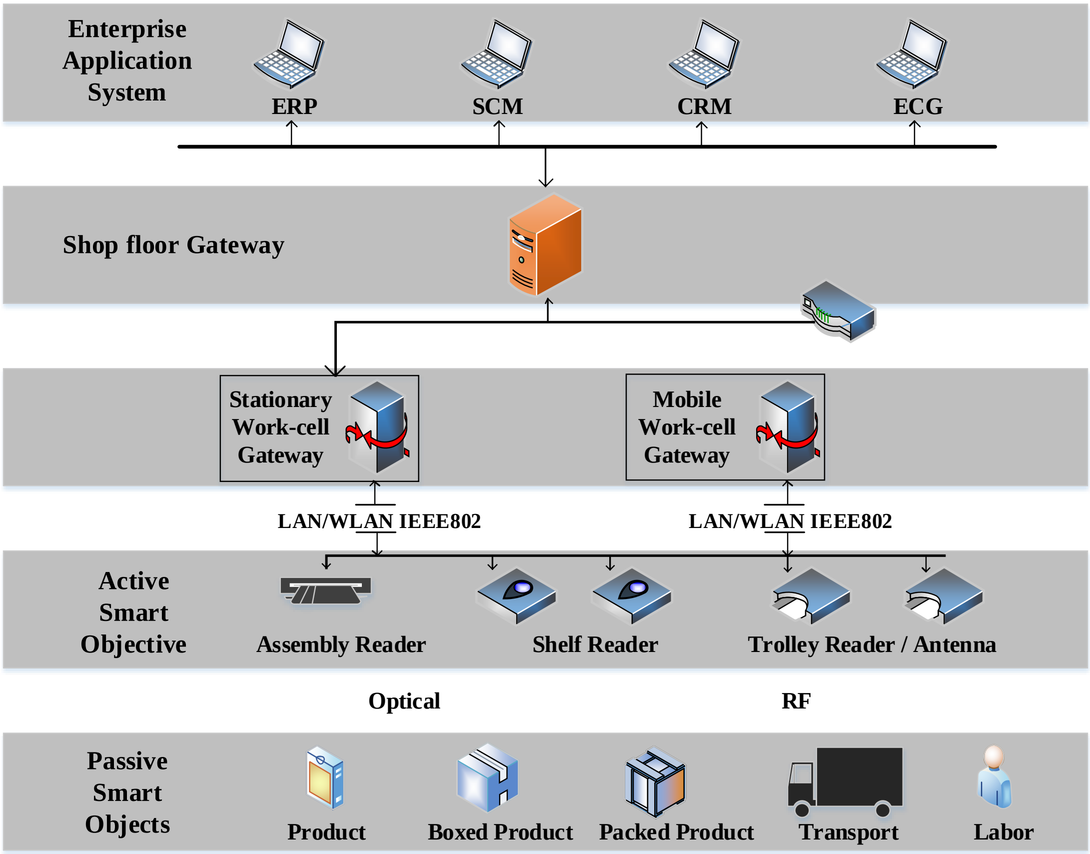

Figure 11. *RFID-enabled ubiquitous manufacturing infrastructure. (Adopted from Luo et al., 2015)*

As it can be seen from Figure 11, the first two layers of this platform are RFID-enabled smart objects. Those objects are called smart since they are equipped with RFID devices. Objects with RFID tags on them are considered passive and those with RFID readers are active smart objects. These objects are able to communicate with each other. Also they are capable of sense, reason, act and react intelligently due to their specific operational logics, data memory and processing functions. Work-cell gateway (WC-Gateway) is another component of UM platform. It consists of a hardware hub and a suite of software systems. WC-Gateway has the role of a server that hosts and connects all RFID-enabled smart objects. In WC-Gateway operating system, smart objects are considered as software agents which are "universal plug and play (UPnP)" and interoperable. And finally there is the Shop-floor Gateway (SF-Gateway) at the center of the overall platform. SF-Gateway provides the mechanism to define, configure and execute different working processes. In other words SF-Gateway's job is to manage the workflow and assist in the configuration of smart objects in different manufacturing processes. (Luo et al., 2015) With these components working together, it can be said that UM platform succeeds at real-time and seamless dual-way connectivity and interoperability between application systems at factory, shop floor, work-cell and device levels.

2.2.3 Challenges of applying RFID technologies in manufacturing

Although promising, applying IoT technologies (RFID technologies in particular) in manufacturing is not without its technological and usage challenges. Yoon et al. (2012) explain in their paper about various problems factories face regarding implementing RFID technologies or in other words embracing UM. The major problems they identify are as follows:

- Tracking the process of products and materials in real-time is challenging. Therefore, sometimes factories have to do manual tracking which delays the work process.
- Nonsynchronous communication between inventory control department and manufacturing schedules leads to no inventory for producing a backlog of orders which generates a time delay.
- Lack of proper real-time monitoring system makes it difficult to collect information about conditions and failures in the system and figure out the reasons for them. So, repair time is delayed.
- Not being able to predict life spans, malfunctions and right maintenance schedule results in managing system through manual input.
- Lack of data compatibility and standardization creates errors when exchanging data between systems.
- Challenges of updating information to the system instantly makes the field situation analysis longer.

Despite all the advancement of implementing IoT technologies into manufacturing, Zhang et al. (2015) explain the remaining challenges in many manufacturing companies. The first challenge is how to build up a thorough information capturing and integration architecture and solution to collect, process and exchange the real-time manufacturing between enterprise layer, workshop floor layer and machine layer. The next challenge is how to effectively set up IoT technologies like RFID sensors to track and trace the manufacturing things during execution stages. The third challenge is how to process and integrate the real-time manufacturing data to achieve consistent dual-way connectivity and interoperability between enterprise layer, workshop floor layer and machine layer.

Even though employing RFID technologies brings some advantages but there are many challenges to overcome for that. Lieshout et al. (2007) elaborate on the challenges companies face for choosing the proper tag/reader technologies. Here is the list of potential problems when factories decide to implement an RFID solution:

- *Large amount of data*: Scanning each RFID tag several times per second by readers creates a large volume of raw data. Processing big data can be challenging.
- *Product information maintenance*: While numerous RFID tags are processed by the reader, the attributes of every tagged product should be continuously retrieved

from a central product database. This process poses a few challenges for large scale implementations.

- *Configuration and management of readers and devices*: Configuring and managing a large number of deployed readers and hardware devices throughout multiple facilities is a big challenge.
- *Data integration across multiple facilities*: With various separated facilities in an enterprise, it is more difficult to manage data in real time and aggregate it into the central IT facility at the same time.
- *Data security and privacy*: Depending on different business applications, security and privacy challenges can have a big impact on the architecture.

Luo et al. (2015) discusses specifically the challenges shop floor managers encounter while releasing the new orders to shop floor. The first challenge is lack of real-time data feedback channel. When shop floor manager dispatches the orders, the manager does not know what happens in the shop floor until the product reaches the last stage. The second challenge is the lack of information-sharing channel between stages. Sometimes one stage may process jobs faster than other stages and does not control the throughput. This results in unbalanced workloads for each stage. The third challenge is the order delay in peak-season and order earliness in off season. This is due to lack of proper coordination mechanism from the upper level to control the order progress within the whole time horizon.

2.3 Internet of Things and process optimization synthesis

Higher efficiency and optimized production allows companies to outperform their competitors. Every manufacturing process faces a common set of business challenges including utilizing assets and resources efficiently, lowering costs, responding fast to changes in market demand and also the need to be able to recognize potential issues in advance and address them for optimal results. (Prokos, 2015)

IoT technologies such as RFID, enables businesses to achieve this high level of optimization by connecting operations and allowing manufacturers to collect data from connected equipment, sensors and devices in real-time. Equipment across the shop floor generates huge amount of data which can be stored in the cloud and used for analysis.

Many academics have studied IoT and the technologies related to it. Also, some research has been done on role of IoT in manufacturing. In this regard, Table 3 demonstrates prominent previous studies which has been used in theoretical part of this research.

Table 3. *Analysis of earlier similar studies with focus on IoT applications in process optimization*

Author	Covered topics	Findings
IoT Applications – Value Creation for Industry		
Schlick et al. (2013)	• Applications of IoT and their potential • Challenges faced by IoT industry applications • Smart factory • Smart product • Automation • Big data • Product tracking • Product lifecycle management	The research recognizes the value of IoT industrial applications in different domains such as: optimizing business process flows based on the big data analysis and optimizing processes based on smart tags and smart objects. Schlick et al. emphasizes that the success of IoT industrial applications depends on extracting relevant information and handling and managing the data along with other factory information and processes.
An Architectural Approach Towards the Future Internet of Things		
Uckelmann et al. (2011)	• IoT definition • Opportunities for IoT • IoT architecture • Process optimization	The article points out that further developments in the IoT will optimize information flow in industrial scenarios. IoT provides more information to companies and facilitates industry management and business processes. Also, the paper suggests a thorough architecture towards a future IoT
The Internet of Things (IoT): Applications, investments, and challenges for enterprises		
Lee & Lee (2015)	• RFID • Wireless sensor networks • Middleware • Cloud computing • Evolution of IoT technologies	This paper categorizes IoT applications into three categories of: monitoring and control, big data and analytics, and information sharing and collaboration. Moreover, the research identifies 5 main challenges for the development of IoT which are: data management, data mining, privacy, security, and chaos
Internet of Things (IoT): A vision, architectural elements, and future directions		

Gubbi et al. (2013)	• IoT definition • Cloud computing • RFID • Wireless sensor networks • Applications of IoT • Future of IoT	The study presents a framework enabled by a scalable cloud to provide the capacity to utilize the IoT. Also, a model of end-to-end interaction between various stakeholders in Cloud centric IoT framework is offered.
Understanding business ecosystem using a 6C framework in Internet-of-Things-based sectors		
Rong et al. (2015)	• IoT definition • Applications of IoT • Future of IoT • Business ecosystem in IoT based sectors	The paper concludes three key component of a IoT business ecosystem: (1) platform provider as the focal firm, (2) product or service, (3) customers or stakeholders who receive feedback from the product or service
Putting things to work: social and policy challenges for the Internet of things		
Dutton (2014)	• IoT definition • Features of IoT • Challenges of IoT	If core values such as privacy and trust are not designed into IoT architecture, IoT could undermine them
Real-time scheduling for hybrid flowshop in ubiquitous manufacturing environment		
Luo et al. (2014)	• Real-time data • RFID-enabled ubiquitous manufacturing infrastructure • Shop floor data capturing • Challenges of implementing IoT in manufacturing processes	Luo et al. introduces smart objects, work-cell gateway and shop floor gate as three cores of RFID-enabled shop floor. They propose a multi-period hierarchical scheduling mechanism which is divide into two levels. The mechanism improves the coordination between decision makers in two levels and efficiently handles the rush orders in the production

First, Table 3 presents the title of each paper and then authors, the topic it covers and its findings. These paper have studies the topics which can help to answer the questions asked in this study. These credible studies offer in-depth analysis of IoT technologies and applications of IoT. And they also discuss the role of IoT in process optimization and how smart manufacturing is possible through implementing RFID technologies.

3. CASE STUDY DESIGN

3.1 Case selection

Qualitative research strategy is mostly used when exploring current or potential products, systems or services. Also it is a great method to look into the strengths and weaknesses of a product or an application such as IoT. Moreover, this method can help to better understand the meaning of the data. Therefore, for conducting this paper, the qualitative research method was chosen.

Case studies are commonly used in organizational studies. According to Yin (2003), the distinctive demand of case studies comes from the desire to understand complicated social phenomena. The reason is that the case study method permits researchers to retain the comprehensive characteristics of events such as organizational and production processes. Case studies provide analytical generalization of theories and it covers a wide range of research methods and techniques including qualitative research method. Therefore a qualitative multiple-case study design was chosen as the method for this paper.

3.1.1 Siemens' Amberg factory

According to Siemens, Siemens Company is the world leader in the market of electronic controls for industrial automation by a significant margin. Siemens' market share has been growing by 1 percent every year for quite some time and Amberg factory plays an important role in this achievement. Amberg production facility manufactures Programmable Logic Controllers (PLC) or as they call it at Siemens 'SIMATIC[11]'.

During the past 50 years, Siemens had been a company on the rise moving towards creating a digital enterprise. Today, Siemens digital factory divisions include factory automation, motion control, product lifecycle management (PLM), control products, eCar powertrain systems and customer services. Siemens is part of the 'Industry 4.0'[12] initiative in Germany among many other giant manufacturers such as ABB, BOSCH and Volkswagen with mutual foundation. The goal is, applying IoT in production and logistics, aiming for (1) getting faster to market, (2) save money in operations, (3) raise productivity throughout the value chain and (4) increasing quality of more complex products. This shapes the future of manufacturing, which involves smart factories and ultimately a

[11] SIMATIC is the product family for automation by Siemens which includes SIMATIC controllers, SIMATIC IO systems, SIMATIC software, etc. (w3.siemens.com)

[12] Industry 4.0 is the application of the internet of things and services in production and logistics. (Bihler, 2015)

digital enterprise platform. In Figure 12 below the gradual expansion of Siemens is shown.

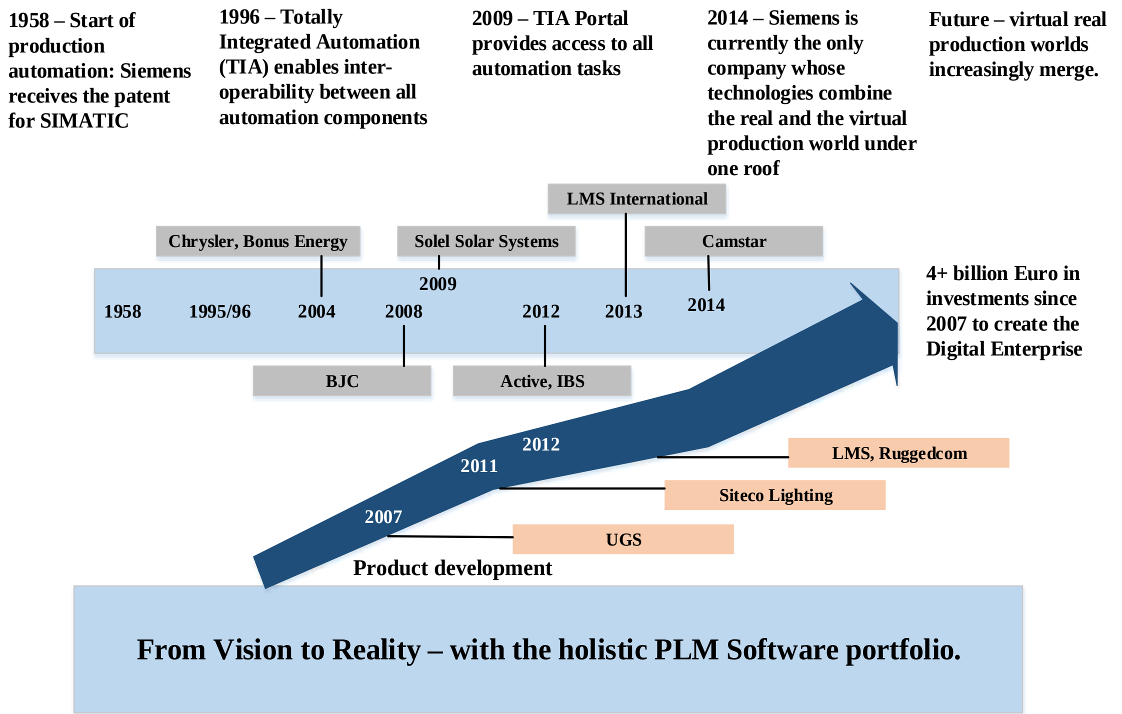

Figure 12. *A history of the systematic portfolio expansion through acquisitions. (Adopted from Bihler, 2015)*

As it can be seen in Figure 12, Siemens has massively expanded its portfolio by acquiring rivals and technology start-ups. Moreover, product development at Siemens is very serious and they have invested more than 4 billion euros to create the digital enterprise since 2007. It started with acquisition of PLM developer UGS. UGS software portfolio included digital production planning tools (Tecnomatix) and market leading PLM solution Teamcenter. The company describes that on a digital enterprise platform, product development and production are integrated step-by-step through industrial IT and industrial software.

In the eyes of Alessi (2014), Amberg plant is Germany’s effort to stay relevant in the digital revolution. He calls EWA, product of a concerted effort by German government, companies, universities and research institutions which is consist of 1,000 manufacturing units communicating through the web with the help of IoT technologies. Therefore, majority of the units in this plant are able to assemble components without further human aid. This is the type of a factory which is capable of manufacturing fully customizable products while they are on the shop floor. This happens when an incomplete product communicate with the machine and tells what services it needs and final product will be put together.

3.1.2 Volvo's Ghent factory

Volvo Cars Corporation (VCC) founded in Sweden in 1927. Volvo is a relatively small player in the global car industry with the total sales number of 373,525 cars in 2010. The company sells cars in 100 countries around the world through its network of local dealers. Historically, Volvo has always had difficulties with collecting customer knowledge since its local dealers control the selling process, and provide sales and after-sales services to customers. In a way Volvo manufactures cars and conducts market research about classes of customers but does not have direct access to knowledge of specific customers. During the past few years, VCC has developed its business model to focus on four digital technologies: mobility, social media, analytics and smart embedded devices. Volvo's intention is to strength its connection with the end-customer without interfering with the relationship that dealers have with their customers. Timo Paulsson, Senior Manager Ownership Services and Brand Protection at VCC explaines "*The last 10 to 15 years, it has been very clear that we need to change our business model to align with competitors*". He adds "*Nowadays, you do not sell a car. You sell a transportation solution, and it should be as efficient and smooth as possible. Looking into the future, we might say we do not sell a transportation solution, we sell an experience*". (Tannou & Westerman, 2012)

Volvo's Ghent factory is located in Belgium. Ghent's optimized production facility has made it an example factory for other plants.

Figure 13. *Ghent factory. (Adopted from hybridcars.com, 2014)*

Volvo Car Ghent had been developing RFID solutions for past 20 years by investing in research to find a concept that fits their production methods. The firm tries to be a pioneer in RFID solutions in automotive manufacturing industry by implementing the concepts into their production sites. (PR RFID im Blick, 2014)

3.1.3 Case selection justification

According to Siemens' website, Amberg factory has won the 1st prize for the "Best Factory / Industrial Excellence Award 2007" in Europe. It came out on top of the categories Operational Strategy, Supply Chain Management, Organization and Personnel, Continuous Improvement, Product Development and Service and Partner Management. The Excellence award proves that EWA is one of the best electronics factories in the world and makes it a perfect case, to study and see how they have managed to reach such high quality.

Recently in an interview with siemens.com (2015), Dr. Siegfried Russwurm, Chief Technology Officer (CTO) and member of the Managing Board was asked about Siemens' strong position in the industry automation business and if Siemens can extend its lead. His reply was: "*We are the only company in the world that already unites the real and virtual manufacturing worlds under one roof – one of the key aspects of Industrie 4.0. We began to orchestrate all components and closely integrate software and hardware 20 years ago, the buzzword being "smart factory". At our Amberg Electronics Plant, products and machines communicate with each other and all processes are optimized and controlled in terms of IT."* He believes that, a perfect example of implementing the Siemens digital enterprise platform is Amberg factory. Moreover, he states "*the production methods we deploy today will become standard in many manufacturing plants in a few years' time."* What it is mentioned above justifies the selection of Amberg factory as one of the case studies for this research and it shows that manufacturing at EWA is already on its way towards the future.

Since 2004, VCC has been strictly following its "one unique tag" strategy when rolling-out RFID globally. Volvo's proven RFID system is fully operating in the production sites in Ghent Belgium and Chengdu China. However the evolvement of the manufacturing processes has made Volvo to do some adjustments to the positioning of the tags. Yvan Jacquet, Project Manager at Volvo Car Gent defines Volvo's vision as "*the integration of RFID tags as a part of the vehicle design*". (PR RFID im Blick, 2015)

Nowadays, car buyers typically request a few custom options for their cars while ordering. Therefore, car manufacturers have to identify and track each vehicle during the whole production process to make sure that all the requested options are installed. To overcome this task VCC uses RFID tags. (Assemblymag, 2014)

In the past, Volvo has tried different methods such as bar code technology during general manufacturing, active RFID in the paint shop, and large bar codes during final assembly line to identify and track each vehicle inside its facility in Ghent. But none of these approaches were reliable enough and they frequently triggered production disturbances throughout the factory. That is why VCC decided to use a more suitable IoT application which is passive ultra-high frequency (UHF) RFID tags in all its manufacturing plants.

Till end of 2014, Volvo installed tags on 2 million cars, along with more than 600 UHF readers to read the tags during production. (Assemblymag, 2014)

Volvo is highly committed to implementing IoT technologies into its production facilities such as Ghent factory. Moreover, its years of experience in working with RFID solutions for manufacturing makes Ghent a perfect case for this research.

3.2 Data collection

The selected method for the empirical part of this paper is qualitative document analysis. The topic of this research is relatively new and therefore majority of references used for this paper are from 2014 onwards. Data were collected from public, non-confidential information sources including press releases, newspapers, articles and journals. All press releases of both case companies involved have been monitored since the implementation of IoT at their plants in order to find the right answers to the questions of the thesis. Moreover, factories' suppliers which had an effective role in their manufacturing processes and ultimately in the case studies have been studies in order to capture the necessary data. All the sources of data for this study were publicly available and collected by the author during Jan.2016 – April.2016. The main sources of information were mostly press releases along with articles, books and credible websites.

For finding the relevant data, some specific keywords were used. The keywords are 'internet of things', 'process optimization', 'real-time data' and 'RFID tracking'. Result of using a single keyword was a large amount of paper which were not all related to this study. Combining keywords helped to narrow down the findings to the most relevant papers. Table 4 presents the list of key data sources used for both cases in this study.

Table 4. *Sources of data collected for the empirical study*

Source types	Most relevant sources	Used sources
Press release	32	20
Article/Report	34	16
Website	5	4
Journals/Magazine	7	2
Book	3	1

As it can be seen from Table 4, most of the empirical study is based on the press releases from Siemens, Volvo and third party companies. The second considerable source is articles and reports that directly addressed the case studies of this paper.

3.3 Data analysis

Data analysis was carried out as the next phase after data collection. The analysis started with the single case analysis and it followed by a cross-case analysis to point out the similarities and differences between the two cases.

The single case analysis was a milestone in this study due to relatively new topics and difficulty of finding most proper data for both cases. First, all the material were studied cautiously. The material included press releases published in the websites of Siemens and Volvo during 01.01.2008 – 26.04.2016. Also the press releases and articles from the suppliers of these companies such as Confidex (an RFID tag manufacturer) were studied in detail.

During the data collection process, every potential material were marked for an in-depth analysis. After reading the potential material, all the useful data were highlighted and documented and based on that, subchapters of the empirical study were designed. The decided subchapters were an introduction about each case factory, followed by implementation and integration of IoT technologies into the production process. And finally the last subchapter for each case is mostly focused on the challenges and benefits of IoT for the facility and what future holds for the company. After carefully reading all the highlighted sources, the empirical part of this thesis was conducted. The empirical part was a concrete base for this paper to draw a conclusion from. Most of the discussion in next chapters after empirical study are purely based on the data from chapter 4. The data were mainly captured from the answers provided by high level managers and factory managers of the case factories in their interviews with journals and other researchers or from the publications of third party firms studying these two factories.

4. CASE STUDY

4.1 Case Amberg

4.1.1 Siemens' facility in Amberg

The Siemens Electronic Works facility in Amberg (EWA), Germany, is a dream plant. The flawless, 10,033 square meters high-tech facility shines with efficient, digital wonder as its smart machines coordinate the production and global distribution of Siemens' Simatic control devices. Amberg site can be seen in figure below. According to Siemens (2015), production at Amberg is a custom, built-to-order process, which involves more than 2 billion components for over 50,000 annual product variations. Siemens sources about 10,000 materials from 250 suppliers to make more than 1,000 different products at EWA.

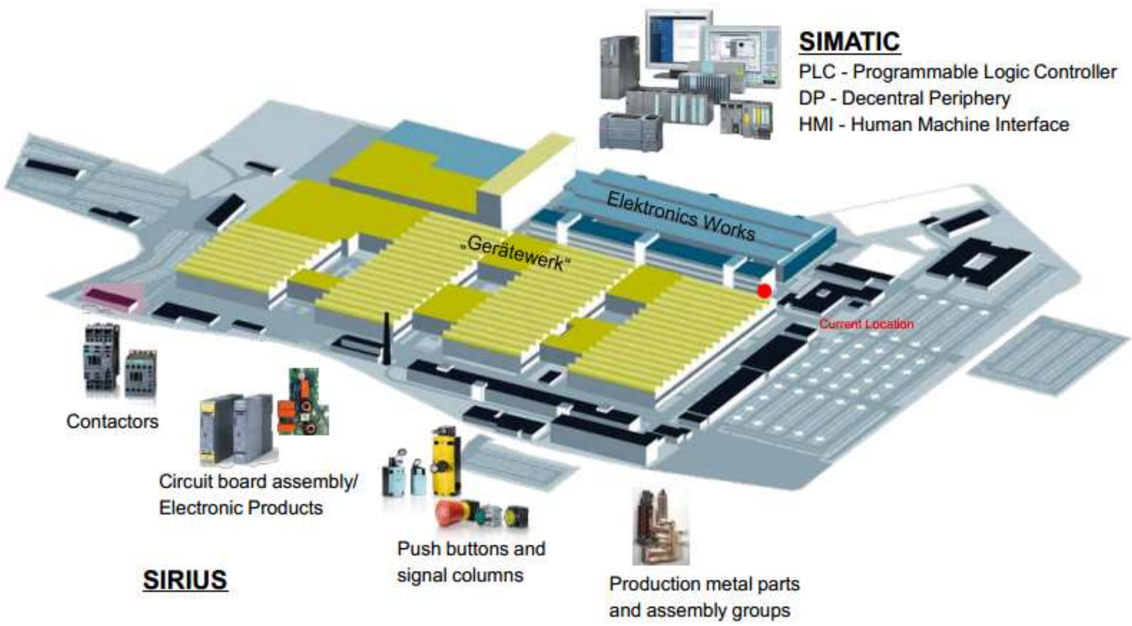

Figure 14. *Amberg site, plants and products. (Adopted from Beitinger, 2015)*

Figure 14 shows different products being produced at Amberg. The light-green parts of the site are equipment plants where production of various parts and assembly activities happen. The blue part is the famous electronics section of the site where circuit boards transform into Simatic products.

According to Siemens, every year more than two billion subassemblies such as resistors, relays and condensers are soldered in this factory. Then Siemens' own Simantic IT makes sure that only components that the customer wants are attached to each circuit board.

Meanwhile, for quality assurance, cameras and x-ray equipment are set up to inspect the quality of the connections. If they spot any issues, workers step in and check the controllers by hand. After that, the product is automatically packaged at the end of the 80 meter production line and forwarded to the shipping center in Nuremberg and from there, 1,000 different products are shipped to more than 60,000 customers around the world. (Siemens' Industry Journal, 2014)

Hessman (2013) explains that the endless variables, extremely complex supply chain and production process at Amberg factory requires capabilities far beyond a traditional factory. He mentions, organizing the material flow and sequencing the processes is a challenging task. And moreover, intelligently managing and scheduling factory's 1,200 employees to meet the requirements of an ever-changing job exceed far past any single technology or any single tool. Basically, machines are used for production, while employees are responsible for programming, control and monitoring those processes with the help of software solutions which represents Amberg's motto "Simantic controls Simantic". According to Hessman, the key factor in making EWA or any other future smart factories work, is creating a solid network of technologies that are integrated and coopering into a smarter, more efficient system. Figure 15, shows the electronic work facility at Amberg.

Figure 15. *Highly automated electronics work facility at Amberg (from siemens.com)*

As it is shown in Figure 15 above, EWA's factory hall is as tall as a two-story building and the area it covers is the size of one and a half football fields. Second floor gives a view of the extremely clean production floor. Aisles are wide enough to easily fit three workers walking side by side, and with the majority of machines no higher than 1.4 meters, there is no problem making eye contact between workers.

According to Siemens' Journal Industry (2014), even though considerable part of the production at EWA is handled by machines and robots, the employees are responsible for the smooth operation of the plant. Siemens foresees increase in automation in upcoming years, but they believe the highly automated production facility will never be able to run entirely without humans as Karl-Heinz Büttner, Plant Manager of the EWA and Vice President Manufacturing at Siemens explains "*people will still be irreplaceable for developing innovation products, planning production, and handling unexpected incidents during everyday operation*." On the other hand, it is not just people who are essential. The quality and efficiency at Amberg are results of benefiting from high-tech machines. For every mechanical tasks done by a human, 5,000 mistakes will be made. Therefore, we are operating at a shy failure rate of 0.5 percent. Looking at defects per million opportunities (DPMO[13]) rate of Amberg factory 25 years ago, it stood at 550 defects per million. But that number was too high for the managers of Amberg factory, especially because a broken controller as a product of the plant can shut down the production of a factory and costs its owners millions of dollars per day. (Jacobs, 2015) Based on a Gartner Industry Research study conducted on EWA plant in 2010, the reliability rate at Amberg factory is at astonishing 99 percent and the plant enjoys a 100 percent traceability on its expensive lines. (Hessman, 2013). The significant improvement of DPMO rate at EWA can be seen in Figure 16 below.

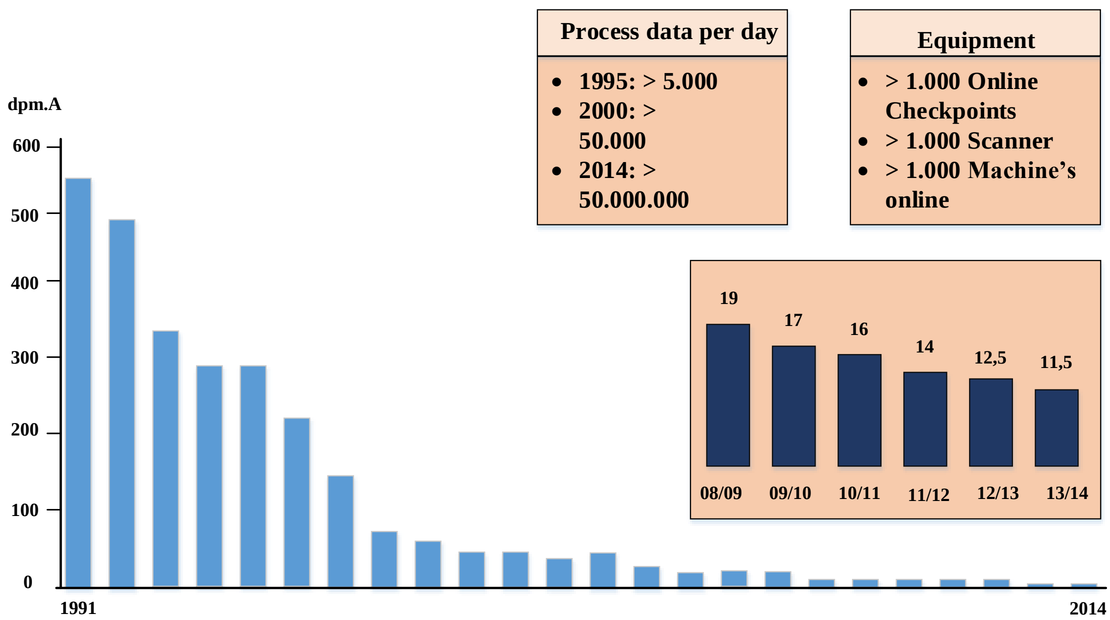

Figure 16. *Perfect result of DPMO rate at Amberg factory. (Adopted from Bihler, 2015)*

[13] DPMO is a measure of the number of errors occurring in a business or manufacturing process. (BusinessDictionary.com)

As it is shown in Figure 16, over the course of 25 years, Amberg plant has enhanced its reliability to almost perfection and this happened throw automation. In 1990, only 25 percent of the shop floor was automated. Siemens' managers decided to move the factory towards a more automated future; today, 75 percent of the shop floor at Amberg factory is automated. Therefore, the defect rate has dropped dramatically to 11.5 per million which means the reliability rate is at staggering 99.99885 percent. On top of that, the output of the factory has grown 8.5 times, while floor space and the number of employees has stayed steady. (Jacobs, 2015) According to Siemens' Industry Journal, EWA ships 12 million Simatic products every year. Considering the factory works 230 days during a year, it means one equipment is completed every second. Amberg plant is a state-of-the-art showcase factory in its field and that is why Büttner said at Siemens 25th anniversary, "*I do not know of any comparable factory in the whole world that achieves such a low failure rate*".

4.1.2 Smart integration at Amberg

According to Helmuth Ludwig, CEO of Siemens Industry Sector North America (2013), the future of smart manufacturing is now. He believes, earlier, different part of the industrial value chain were implemented separately, including product design, production planning and engineering, production execution and services. But today, these worlds are brought together by new technologies. He explains the reason why Amberg plant is thriving is the integration of three specific crucial manufacturing technologies: product lifecycle management, industrial automation and manufacturing execution systems (MES). (Hessman, 2013) Each of these technologies and its application at Amberg is explained below:

Product lifecycle management: PLM is "managing all data relating to the design, production, support and ultimate disposal of manufactured goods." (Product-lifecycle-management.com, 2016) Siemens' definition of PLM is "an information management system that can integrate data processes, business systems and ultimately people in an extended enterprise." Siemens uses PLM software to efficiently manage the information during the entire lifecycle of a product, from ideation to design and manufacturing and finally service and disposal. Siemens believes PLM software allows companies to realize innovation and their PLM software products portfolio includes: Teamcenter, Active Integration, NX, Solid Edge, Fibersim, Syncrofit, Seat Design Environment (SDE), Femap, LMS, Quality Planning Environment (QPE), Tecnomatix[14] and PLM Components. At EWA, before purchasing Tecnomatix PLM software, they were facing a few challenges including products in many quantities and customer-specific variations, increasing cost and

[14] Tecnomatix is a comprehensive portfolio of digital manufacturing solutions that help you realize innovation by synchronizing product engineering, manufacturing engineering and production. (www.plm.automation.siemens.com)

time-to-market manufacturing lines, and worldwide manufacturing lines. Peter Engelhardt, a manufacturing planner at Amberg explains that as a leading factory, Amberg had problems with giving manufacturing planners a more systematic way of working. He mentions "*the minimal level of data integration on our old process caused us additional work, along with the labor required to trace out and provide proof of the outcomes for the planning work*." Amberg plant was aiming to considerably reduce the effort needed for manufacturing planning of product variants along with increasing workloads with higher efficiency. Moreover, they were eager to improve the quality of individual project reports in order to facilitate management decisions and simplify the understanding of production process changes. To achieve these goals, Siemens Industry Sector's IA CD unit purchased the Tecnomatix digital manufacturing solution from Siemens PLM Software which fulfilled these goals in a step by step approach by nearly 100 percent. Tecnomatix offered assembly planning and validation capabilities which made it possible to evaluate manufacturing methods, calculate production costs, schedule resources and examine resource utilization. (www.plm.automation.siemens.com) The impact of implementing PLM software at Amberg plant is summarized in table below.

Table 5. *PLM software application at Amberg factory*

Product	• Tecnomatix
Business initiatives	• Production efficiency
Business challenges	• Products in many quantities and customer-specific variations • Increasing cost and time-to-market pressures • Worldwide manufacturing lines
Keys to success	• Tecnomatix as the standard tool for manufacturing planning • Simulation for assembly planning and material flow • Interface between planning tools and SAP
Results	• Standardized planning processes across worldwide manufacturing locations • Consistent data for decisions about manufacturing locations and product introductions • Better control over manufacturing process changes

Industrial automation: According to Omer (2014), industrial automation is defined as "a set of technologies that results in operations of industrial machines and systems without significant human intervention and achieve performance superior to manual operation."

According to Siemens' website, at Siemens, industrial automation is called Totally Integrated Automation (TIA). It is a name given to efficient interaction among all the automation components. TIA is Siemens's answer to the demanded high level of efficiency at the engineering stage, as the first step approaching faster, production becomes more flexible and more intelligent. TIA is a portal that offers an integrated engineering framework and best possible support for optimizing all plant, machine and process sequences. TIA portal provides a standardized and dependable operating concept. It integrates controllers, distributed I/O, human-machine interfaces (HMI), power supply, drives, network components, motion control and motor management in a single engineering environment; therefore, it covers the whole production process. TIA is based on the constant presence of consistent data management, global standards and uniform hardware and software interfaces. These characteristics result into minimizing engineering time which leads to lower costs, reduced time to market and higher flexibility.

Manufacturing Execution Systems: MES is the link between the production and management levels which provides higher transparency throughout the plant. In other words, MES is the core element connecting PLM to Automation (Figure 17) and providing manufacturers with a real-time industry software layer.

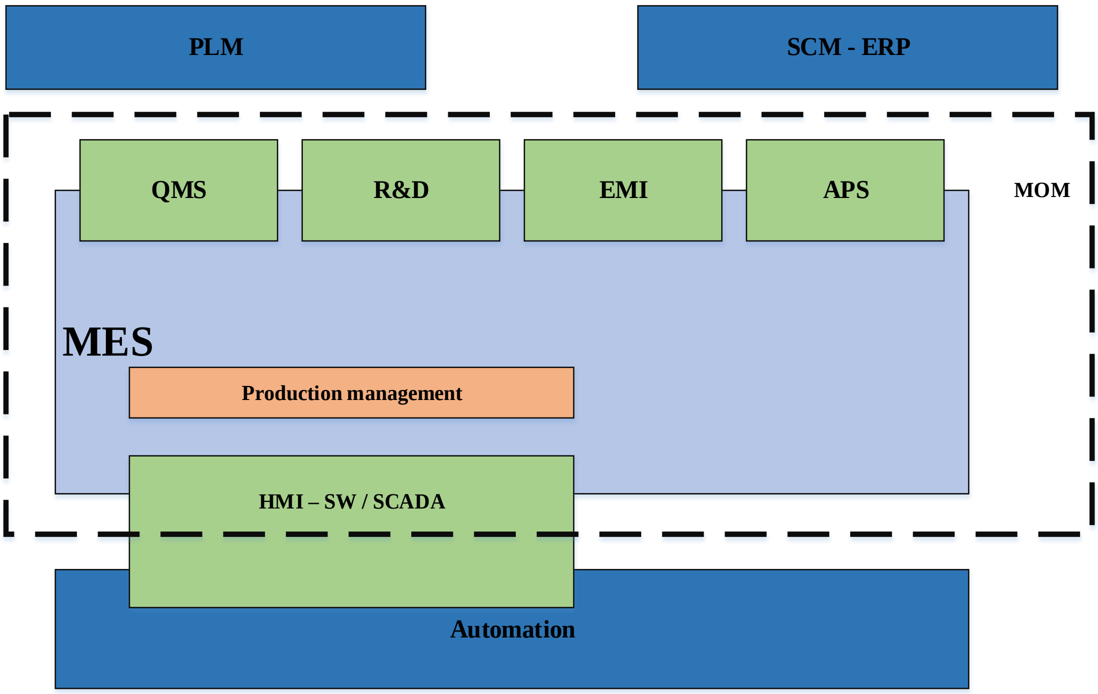

Figure 17. *MES, the link between PLM and Automation. (Adopted from siemens.com/mom, 2015)*

As it is shown in figure above, Siemens' MES is a part of its Manufacturing Operations Management (MOM) system. MOM is an integrated approach to improving the performance of manufacturing operations and it standardizes and optimizes manufacturing processes to minimize lead times, optimize asset utilization, reduce global time-to-market and increase production visibility. Management execution system at Siemens is called SIMATIC IT Production Suite. SIMATIC IT at Amberg plant offers its single components that enables manufacturing processes and operating procedures to get synchronized and coordinate accordingly.

Together, PLM, TIA and MES create a powerful software suite for Amberg plant which connects all the levels from field, control and operator levels to management level and finally enterprise level. The plant employs the latest tools, such as NX, Tecnomatix, Teamcenter and PLM programs for production development. Also, MES software, Simatic IT, a large number of Simatic controllers and RFID systems are used for production processes. These products are linked through interfaces with enterprise resource planning (ERP) systems. (Wegener, 2014) This helps the seamless integration of data from development, production and suppliers along the industrial value chain.

4.1.3 Internet of Things at Amberg

Anders Gustafsson, CEO of Zebra Technologies, calls the internet of things "an exponential explosion of connected devices." He says, IoT gives a digital voice or a virtual voice to all physical things. Then the digital voice enables them to communicate something about themselves, for instance what they are, their condition, where they are and more. As it is explained in the Gartner report, inside Amberg facility, there are touchscreen HMIs that permit users to drill down from time-based performance trends to individual product lines and levels. This enables the process of tracking performance and in-depth root cause analysis of over 400 points of automated data collection. (Hessman, 2013)

Based on press releases of Siemens, due to manufacturing large number of different products at Amberg plant, the facility has to operate at maximum efficiency to remain competitive. Over the time, it has become harder to organize the production sequences in a way that an economical production is possible. Engineers at EWA has found the solution in a process flow that is fully adjusted with the product variation using IoT technologies. According to Bartneck et al. (2009), by adding a new production line to the facility in 2009, Siemens' goal was maintaining high production quality while manufacturing a large number of variants. They were aiming for more flexibility, lower cost and higher quality production.

At Amberg each product is considered as a unique specimen and they are not treated as mass production goods. This approach has become possible by a flexible production, where each workstation and each machine is able to process a lot of different products. At EWA, this process starts with flexible mounting machines for manufacturing printed circuit boards and ending with packaging workstations where the assigned accessory items for every product are shown on the monitor, their removal from storage bins is checked. After analyzing production processes, managers at Amberg chose RFID and barcodes as potential technologies for their business. After comparing the two technologies, the results proved that RFID is a far better option for Amberg. The qualitative benefit of RFID in detail can be seen in table below.

Table 6. *Benefits of RFID technology over barcode technology at Amberg factory.*

Benefit	Description
Increased quality	• Manufacturing dates constantly updated on the RFID transponder • The RFID transponders are written with information from current QA results • Faulty components are automatically sorted out and the error directly eliminated • Components are returned to the assembly process following correction
Increased speed	• Increased throughput speed – due to “Data on tag” which results in fast data transfer • Reduction of set-up time – due to “Data on tag” (writing production data on the transponders), the production control system is triggered directly
Reduction of the use of IT	• Managing without implementing a database by using “Data on tag” • Focusing the employees on high system availability, timely error correction, and concluding quality assurance

Moreover, Siemens experts at EWA plant implemented a cost estimation to quantify the benefits of each technology. As it is shown in table below the costs for barcode technology were around 35,000 euro lower than for RFID technology.

Table 7. *Barcode and RFID costs at Amberg factory*

Item	Barcode solution	RFID solution
Reading devices	EUR 50,000	EUR 60,000
Transponder	-	EUR 40,000
Software (including integration)	EUR 5,000	EUR 15,000

Extra IT expenses, output devices	EUR 25,000	-
Proportional project costs	EUR 40,000	EUR 40,000
Total costs	EUR 120,000	EUR 155,000

Even though the total cost of implementing RFID technology was higher than its rival, due to its increased system production capacity, it was feasible to overcompensate the higher investment in RFID.

At Amberg facility, engineers have utilized IoT technologies to implement a self-organizing production which prioritizes and enters jobs into the production network. The production employs specific work-piece carriers which are well equipped with SIMATIC RF300 type RFID transponders. (See Figure 18) What this system offers is that it enables data to be retrieved remarkably fast, and therefore the work-piece does not have to stop at the reader. The transponders contain the building plan, which allows automatic testers to run an individual test program for every device. Then the results and other related data are stored on the RFID chip or transferred to the control systems by PROFINET[15] network.

Figure 18. *Range of Siemens' SIMATIC RF300. (From siemens.com)*

Typically, as the number of variants increases in the production flow, the utilization of the machines decreases. Amberg factory has overcame this obstacle by replacing machines involved in decision making of production steps with trained, skillful workers equipped with RFID technology. Through RFID chip, workers receive precise instructions on the touchscreens regarding what to do with specific work-piece. (See Figure 19) The solution is that each work-piece carrier of the assemblies is equipped with data me-

[15] PROFINET is the leading Industrial Ethernet standard and makes companies more successful by accelerating processes, boosting productivity and increasing plant availability.

dium MDS D422 passive transponder made by Siemens. This transponder has the capacity of 8 Kbyte and can be written to and read unlimitedly. After the selection of a pending production order, the corresponding data record is automatically written to the transponder. The data includes the production identification and also the exact product-specific timetable and work plan.

Figure 19. *RFID supported production at the Siemens plant in Amberg. (From Bartneck et al., 2009)*

Then the record is read and evaluated at the individual processing modules. The reader is connected to module controllers via the product family SIMATIC RF200. After the evaluation, the necessary work steps are automatically initiated and when production step is completed, the production and quality data can be added onto the transponder. Therefore, in the production line in Amberg factory, the parts do not have to always be moved sequentially through the line, instead they can be transported back to upstream stations. Combining material flow and manual processing stations has led the plant to an efficient, utilization-controlled and yet greatly flexible production line. What makes EWA a special factory is that they have achieved higher efficiency and utilization while expanding production plan. (Muller, 2012)

4.2 Case Ghent

4.2.1 Volvo's facility in Ghent

These days RFID as a popular identification technology in non-contact data transmission scene. However, RFID is already well established in automation and especially in automotive industry as a pioneer. For instance, RFID data carriers are built into or installed on vehicles for the purpose of production control. (Logident Press Release, 2009)

According to Volvo, from 2000 to 2010, the company was owned and involved with Ford Motor company as a joint organization and later on in 2010 it was bought by Chinese firm Zhejiang Geely Holdings Group. One of the largest assembly plants in the portfolio of Volvo Cars Corporation is Ghent factory. It assembles more than 35,000 vehicles per year. Moreover, Ghent is the home to the VCC's world's largest spare parts distribution center for trucks, buses, construction equipment and marine and industrial engines. With typically have more than 200,000 spare parts in the warehouse, the facility handles over 6.8 million orders per year. (iMinds, 2014)

Alec Paepens, Network Manager at Volvo Ghent, in his interview with iMinds on October 2014, discussed about stable wireless communication and installation of IoT applications at Ghent factory. He mentioned that the factory uses technology for instant request of refilling parts on the line. Also Ghent owns a large fleet of Automated Guided Vehicles (AGVs) driving around the facility with chassis which are equipped with wireless trackers and sensors and fully connected by antennae. (iMinds, 2014)

At Volvo factory in Ghent, after the discontinuation of the outdated identification system in the finishing industry, managers' focus was on the entire production chain from the body plant phase to the final assembly stage. Ghent's main goal was to introduce a universally applicable identification technology. From 2006 to 2008, decided to review its approach totally. Jacquet explains: "*to do so we had extensive previous experience and built up our knowledge from the beginning. It took 6 years till we managed to develop a complete solution. During these years we tested 80 prototypes and over 50,000 tags in the process. We developed the tag and the reader but still had to be adopted to overcome interferences and reflections caused by metal*." (PR RFID im Blick, 2014) Therefore, instead of 2D-barcodes, VCC decided to choose passive UHF-RFID technology. The new technology had significant advantages due to its range and the flexibility to extend use to other applications. The UHF reader (Figure 20) enables the use of customer-specific applications and middle-ware functionalities precisely on site in the reader unit.

Figure 20. *UHF reader at Ghent production line. (From logident, 2009)*

At Ghent, all three of the reader, PC and antenna are in a single housing. Because this makes the installation much easier and also protects the antenna against severe operating conditions such as humidity, high temperatures and flying sparks. Till 2009, there were 85 readers installed in the body plant, generating around 85,000 read events per day with the impressive reliability of 99,99 percent. (Logident Press Release, 2009)

Today, Ghent factory uses only one passive UHF transponder tag from the first stage of the process line. This tag is a disposal tag which stays intact on the car from the welding and paint shop stages to the final assembly shop and it is still used when the car leaves the plant. By May of 2014, over 2 million cars were built on that concept in Ghent factory. (PR RFID im Blick, 2014)

4.2.2 Implementation and application of IoT in Ghent factory

The controllability of a factory is greatly dependent on the interaction between enterprise resource planning system and shop floor, and the capability of any authorized user to review the status of sales orders on the shop floor. Business and plant systems should be combined to shorten decision making process, improve plant productivity as well as eradicating human intervention to increase accuracy and data availability speed. (Ghannam et al., 2014)

Today, a car manufacturer like Volvo has to adopt itself to the diversified consumer requirements while at the same time increasing production volumes and lowering costs. The fact that many customers order various options while purchasing their cars, makes many cars unique in the production line. At Ghent, the production is even more complicated than other plants because several different models are assembled in the same production line. That is why Ghent factory relies on IoT applications to identify and reliably track every car during the whole production process to manage such a variety of products. In case of Ghent plant, Volvo uses RFID technology to raise its production. Confidex (the Finnish RFID tag manufacturer) developed a robust passive UHF RFID tag for Volvo to track its production assets during all stages of production. (Miettinen, 2014) By taking this approach, Ghent changed four important functions in its production process. First, changing the functional models which developed to manage the static basic information. Second, the functions used to collect the data from shop floor and warehouse in real-time. Third, the functions developed for production planning and scheduling. And finally, the functions which are used to combine the real-time information with the decision-making models. (Pan et al., 2012)

Volvo has always had a clear RFID strategy to use one permanent tag throughout the entire production line. The Confidex Corona tag can be seen in Figure 21 below. The tag is affixed to the shock absorber system (crash box) below the bumper which is located on the chassis above the front tyre and will stay there during the whole production process. (PR RFID im Blick, 2015)

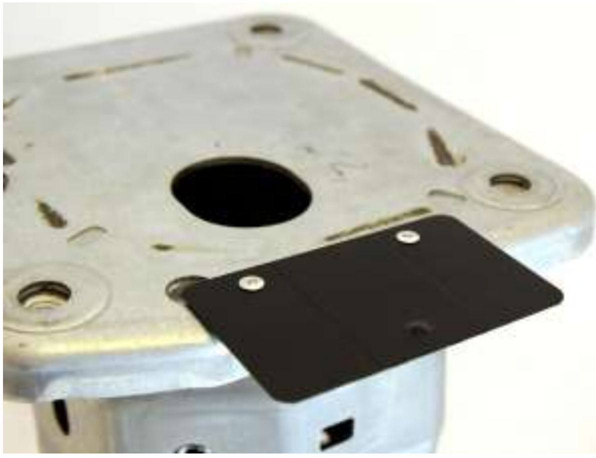

Figure 21. *Corona tag affixed on a chassis. (From Confidex.com, 2016)*

IoT comes into play the moment chassis receives an RFID tag. At Ghent, a chassis passes an RFID reader in the production line, the tag ID number and the information saved in it is recorded and transferred to the backend system. The software which runs on any reader, interprets the read events, filters false data and transfers the relevant information to the middleware. Then, the middleware passes this data to the backend system. The chassis goes through a series of data points[16]. In each data point, a record is generated which documents the stages that have been carried out. Meanwhile, the software manages and monitors the RFID hardware and software status simultaneously. A simplified product identification process is shown in Figure 22.

[16] Data point is the place where a specific type of data needs to be read or a control data needs to be injected. (Ghannam, 2014)

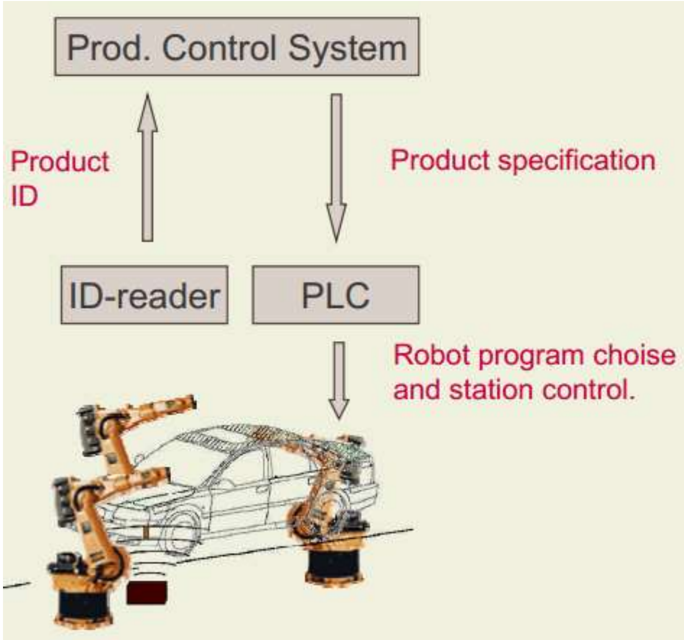

Figure 22. *Product identification process at Ghent. (From Olsen, 2010)*

Figure 22 is a response to mass customization of products at Ghent which forges a need for product identification and IoT solutions to be able to control the manufacturing process. After leaving the welding shop, car-bodies move to the paint line which is the harshest environment for the tags used. As the car-body with attached tag moves through the paint line, it passes a reader which verifies a unique ID for the body and the control system instructs the automatic spray booth what is the right color to paint the specific car (See Figure 23). (Nathan, 2015)

Figure 23. *Paint line at Ghent factory. (Volvo Car Corporation, 2014)*

Moreover, on the paint line, the car goes through an electrolyte bath for corrosion prevention, several layers of paint and a series of high temperature drying ovens. It is crucial that the RFID tag remain readable and reliable in these severe conditions. (Miettinen,

2014) Jacquet explains that Volvo had developed a platform solution for all of its six car models. All the reading points of the RFID system on the assembly line are installed in a way that tags are read in the same position every time. During the finishing process, cars are driven to the parking lots and the RFID data capture continues there also. For vehicle identification, stationary readers are installed at the gates, passages and parking areas. During the parking process UHF tag and parking space are read by the driver with a handheld reader to collect the vehicle location. (PR RFID im Blick, 2015)

To sum up the smart implementation of IoT application at Ghent factory, the work-in-process (WIP) is always monitored by a tag affixed on the chassis that moves through the production line as it is planned by ERP. By using this RFID solution, Ghent plant is able to track the progress in real-time on the floor shop with the help of the readers at each work station. This provides Ghent a full visibility of the WIP data across all processes and stations and makes the decision making process smooth and ultimately an optimized production.

4.2.3 Challenges and benefits of IoT at Ghent factory

Implementing new applications and making them work for the factory has its own challenges. Jarkko Miettinen, Vice President of sales at Confidex, Mentions: “Automotive production is one of the most challenging applications for RFID not just because of its complexity, but also due to its uncompromising, high-reliability requirements.” Furthermore, Mark Higham, General Manager of Process Automation at Siemens, addresses general challenges of adopting RFID technologies as tag cost and customer nervousness in adopting this new technology. The reason is there might be concerns about reader consistency. It is managers’ job to analyze the situation and come up with the solutions to minimize the concerns and make those applications possible. (Nathan, 2015)

Alec Paepens and Kris Van Cauwenberge, Technical Support Manager at Volvo, count three challenges they face at Ghent factory regarding the implementation of RFID solutions. Cauwenberge believes the biggest challenge is the ever changing geography of Ghent’s warehouses and production lines. At the warehouse, wooden containers full of metal parts are stacked up. Those act like walls which move and change frequently. That has a serious negative impact on wireless coverage. And also the factory cannot afford to continually redeploy cables and move access points due to restricted time and advanced planning. Moreover, managers cannot use AGVs and wireless-enabled forklifts to maintain a connection because the speeds they move at. Paepens thinks that security is also a big challenge. He explains that a secure network is a necessity at Ghent due to large amount of automation and proprietary information flowing back and forth. But having a stronger security infrastructure means it is more complex and maintaining successful wireless connections becomes more challenging. He states: “*there is also the interaction between clients and access points, which are usually made by different companies. It* *should not be an issue, since providers are supposed to be consistent with IEEE*[17] *standards. But unfortunately in our experience, that is not always the case which can cause problems with devices, clients and access points establishing and maintaining robust connections.*" (iMinds, 2014)

According to PR RFID-im-Blick Intl (2015), the project manager at Ghent discusses an ongoing challenge at the factory. He explains that there has been a change in assembly process of some models. The spot on the car body which had been used for the tags so far is not available anymore in the welding shop, because bumper beam will be placed in final assembly shop. As a result, factory has to relocate the tag during process. Also the transponder is surrounded with integrated electronics such as sensors. It gets significantly harder to guarantee the UHF reading performances that leaves Volvo with the question of which transponder position is optimal for consistent identification.

NXP (2013) has made a comparison between RFID and older technologies such as barcode scans to point out the benefits of RFID. Four bold advantages of RFID over other technologies are:

1. RFID reads are much faster that barcode scans in identical setups. This is a significant benefit for production lines with many stations since saving time results in lowering labor costs.
2. The RFID method is much more accurate which leads to less scrap.
3. Customization of similar products for different customers will be easier by using RFID technologies.
4. There is no need for line of sight to read RFID tags.

Implementing IoT applications at Ghent factory has had positive impacts on the plant also. Cauwenberge believes the rise of internet of things has changed production at Volvo. As one massive benefit of this phenomena, he mentions that equipping conveyers, automatic strapping machines and warehouse vehicle with intelligent sensors is a great boost to the production at Ghent. Cauwenbege adds: "*we have got over 300 forklifts that require manual maintenance. We are able to only service them and check for technical problems when they are not being used, which is not enough time.*" By benefiting from IoT-enabled technology, Ghent is able to employ a proactive approach to maintenance, collect performance data in real-time so that they can prevent problems before they shut down the vehicles or production installations.

Paepens describes another advantage that IoT brings in Ghent factory which is complementing forklifts with devices and sensors for tracking and picking purposes. Ghent plant needs intelligent machines and an intelligent network in order to embed intelligence into

[17] IEEE is an organization that develops global standards in a broad range of industries, including power and energy, automation, information technology etc.

the system. He adds: “*We can do more work, higher quality work, and increase productivity to attract new models to the plant.*” (iMinds, 2014) Moreover, real-time information enables warehouse operators to minimize material delivery delays. Earlier, the shop floor operators were sometimes unaware of out of stock materials. But now the real-time information will automatically set off an alarm to inform the warehouse operator about the assigned delivery task. Having access to real-time information, enables managers to make better decisions and ultimately improve the responsiveness to everyday market and engineering changes, in addition to the shop floor productivity and quality. (Pan et al., 2012)

4.3 Cross-case analysis

During the cross-case analysis the major similarities and differences between two case studies are emphasized. The comparison is made according to the background of case studies and their level of involvement with IoT technologies. The cross-case analysis is based on the data provided in previous chapters and author’s perception of the cases.

After studying Siemens’ Amberg factory and Volvo’s Ghent factory, it was apparent that they have some big differences and a few similarities in terms of using IoT technologies, IoT solutions and challenges of implementing IoT applications into the production process. Each of these differences and similarities are categorized and discussed below.

First category is the level of IoT integration. After an in-depth analysis of both case studies, it was noticeable that there is a big gap between the level of IoT integration between Amberg factory and Ghent factory. As it is explained in section 4.1.2, Siemens’ PLM portfolio in use at Amberg factory includes Teamcenter, Tecnomatix and the TIA Portal as a unified interface for MES and PLCs. Teamcenter is the most successful solution in the industrial market for product data management which offers more efficient manufacturing process to Siemens’ factory. On the other hand, as it is mentioned in section 4.2.1, Volvo Cars was integrated with Ford for ten years and it was involved in shared work processes in many areas including PLM portfolio. Today as an independent company, Volvo is reviewing its work process and is determined to choose the best software solutions to integrate IoT applications into its production. According to Siemens’ website, Volvo Cars is planning to employ Tecnomatix and Teamcenter products into its facilities as it recognizes the benefits of using the manufacturing process management capability of Siemens PLM solution.

Second category is software and hardware challenges. It is safe to say that large portion of challenges at Amberg factory are related to software. However, at Ghent factory, managers face challenges related to both software and hardware. At Amberg, there are still some weak spots that need higher level of standardization in integration of PLM, MES and ERP solutions. That is one crucial reason for Siemens’ aggressive acquisition approach. (See Figure 12) On top of Volvo’s software challenges explained above, continuous evolvement of product design and factory layout are two hardware related challenges that Ghent managers face daily. Modifying the design of the product and phases of assembly plan has been a serious issue at Ghent, since engineers have to figure out another suitable spot to attach the RFID tag to the chassis. Moreover, changes in the layout of the facility affects the quality of data transfer on the shop floor due to lack of wireless coverage.

Third category is customization. Customization is one of the mutual aspects of these two case studies. As it is mentioned in section 2.2.1, IoT technologies enable businesses to customize their products efficiently and profitably. This study shows that both Amberg and Ghent factories are involved with high level of customization. Production at Amberg is a custom, built-to-order process, which involves more than 2 billion components for over 50,000 annual product variations. As it is explained in section 3.1.1, majority of units are able to assemble components without further human aid. This is the type of a factory which is capable of manufacturing fully customizable products while they are on the shop floor. Nowadays, car buyers order a few custom options for their cars while purchasing. Therefore, a car manufacturer like Volvo has to identify and track each vehicle during the whole production process to make sure that all the ordered options are applied. (See section 3.1.3) At Ghent, the production is even more complicated than other plants since several different models are assembled in the same production line. That is why Ghent factory relies on IoT applications to identify and reliably track every car during the whole production process to manage such a variety of products. (See section 4.2.2)

Forth category is customers of the two factories. Volvo's Ghent factory covers both B2B and B2C contexts while Amberg factory is purely focused on B2B. Amberg produces Simatic programmable logic controls which are used to automate machines and equipment in order to improve product quality and the products are purchased by other manufacturing companies. (See 4.1.1) On the other hand, Volvo's strategy includes both B2B and B2C. As it is discussed in section 3.1.2, Volvo sells cars through its network of dealers or other middle companies but during past few years, Volvo's goal has been strengthening its connection with the end-customer without interfering with the relationship that dealers have with their customers.

5. DISCUSSION

In this chapter, the key findings of this study are elaborated. It demonstrates how thoroughly the objectives of the thesis are met. The answers to the main research questions of the thesis are explained in this chapter. Also, this chapter provides a detailed comparison between empirical findings of the study and the literature review. The summary of the comparison is shown in three tables for easier comparison.

The three main questions of this research to answer are:

1. How can manufacturers use IoT technologies in optimizing their production process?
2. What are the benefits of using IoT technologies on shop floors for factories?
3. What are the challenges and issues of implementing IoT into existing businesses?

5.1 Question 1. How can manufacturers use IoT technologies in optimizing their production process?

Based on the literature review of this study, IoT technologies are proved to be an influential help in production processes. They facilitate the process in many ways for manufacturers. As it is discussed in chapter 2, generally, the abilities of IoT technologies to impact production processes are categorized into four groups of: monitoring, control, optimization and autonomy. Below, each group is briefly discussed to make possible the comparison of literature and case studies:

In monitoring, sensors and external data sources enable the thorough monitoring of product's operation and usage, product's condition and external environment. It also enables alerts and notifications of changes. The second group is control which happens through the software embedded in the product or in the product cloud. The software allows control of product functions and personalization of the user experience. The next group is optimization. The purpose of optimization is enhancing product performance and allowing predictive diagnostics, service and repair. To elaborate more, monitoring and control capabilities facilitate algorithms that optimize product operation and use. Autonomy is the last group. It is the combination of three previous groups. In other words, combining monitoring, control and optimization allows autonomous product operation, self-coordination of operation with other products and systems, autonomous product enhancement and personalization, and self-diagnosis and service.

Products at Amberg factory are made in many varieties based on the demands of the customers. And this needs a flexible production capable of many variants. Machines and pick-and-place equipment should be automated enough so that manufacturing various products is possible. This is what IoT technologies provide for Amberg factory. RFID systems improve flexibility and as a result the productivity of the plant. They are considered as significant factors in production and logistics. Therefore, at Amberg, customized products are manufactured flexibly and fast. What IoT technologies offers to the factory is a reliable identification system and a high performance network. These key offerings enhance the simulation of production sequences, the engineering automation, the production planning and supply chain management systems.

At Volvo's Ghent factory, IoT technologies such as RFID solutions, wireless networks and cloud computing provide an overall more flexible production to respond to global consumer demand. RFID solutions make the production process faster and more reliable, so the cars reach the market quicker. At Ghent, IoT technologies combine information, technology and human skills to deploy manufacturing intelligence into every aspect of production process. All of this leads to a more optimized and a more efficient plant which is able to react to changes in real-time by continues monitoring and control of the production. Moreover, warehouse management and logistics at Ghent have improved considerably.

After answering question 1, the answers provided in theoretical part and case study part are compared in the table below. The shared answers discussed in both theoretical and empirical parts are colored in green.

Table 8. *Barcode and RFID costs at Amberg factory*

Theoretical studies	Case studies
Control	Monitoring
Monitoring	Flexibility
Optimization	Optimization
Autonomy	Efficiency

As it can be seen from Table 6 above, answers from both theoretical and empirical studies mostly cover the same topics. An argument can be made that combining four factors of monitoring, flexibility, optimization and efficiency results in autonomy.

5.2 Question 2. What are the benefits of using IoT technologies on shop floor for factories?

As it is discussed in theoretical part of this paper, IoT technologies brings many advantages to the shop floors. IoT will create many opportunities for plants by enhancing data collection, enabling real-time responses, increasing efficiency and productivity, and improving access and control of devices.

Through IoT, frequent data collection will be possible and then, these data can be used to optimize outcomes. Another benefit of IoT is that, the data can be collected instantly which makes the real-time decision making happen and afterwards necessary actions will be taken. This would have a positive impact on WIP at shop floor. By capturing real-time information, it is easier to make sure production line runs smoothly and efficiently and the lack of spare parts or raw material on the line will be minimal. The next benefit of IoT is in enhancing productivity at a larger scale where coordination of numerous pieces is crucial. This is due to IoT's ability to provide better access and control over Internet-connected devices.

Due to manufacturing large number of different products at Amberg plant, the facility has to operate at maximum efficiency to remain competitive. Over the time, it has become harder to organize the production sequences in a way that an economical production is possible. The IoT technology that runs the shop floor at Amberg is a RFID solution. By using RFID, each product is considered as a unique specimen and they are not treated as mass production goods.

At Amberg factory, IoT technologies offers high quality production, faster production and reduction of IT usage to Siemens. The increased quality is due to manufacturing dates being constantly updated on the RFID transponder, faulty components are automatically sorted out and the errors directly removed and then those components are returned to the assembly process following correction. The increased speed is because of faster data transfer and reduction of set-up time due to data on tag. And finally, reduction of IT usage eliminated the need of a database for shop floor management and also lowers the error rate.

Implementing IoT applications at Ghent factory has had positive impacts on the plant. An important benefit is equipping conveyers, automatic strapping machines and warehouse vehicle with intelligent sensors which is a great boost to the production at Ghent. By benefiting from IoT-enabled technology, Ghent is able to employ a proactive approach to maintenance, collect performance data in real-time so that they can prevent problems before they shut down the vehicles or production installations. Earlier, the shop floor operators were sometimes unaware of out of stock materials. But now the real-time information will automatically set off an alarm to inform the warehouse operator about the assigned delivery task. Having access to real-time information, enables managers to make better decisions and ultimately improve the responsiveness to everyday market and engineering changes, in addition to the shop floor productivity and quality.

After answering question 2, the answers provided in theoretical part and case study part are compared in the table below. The shared answers discussed in both theoretical and empirical parts are colored in green.

Table 9. *Barcode and RFID costs at Amberg factory*

Theoretical studies	Case studies
Data collection	Data collection
Availability of real-time data	Availability of real-time data
Enhanced productivity	Enhanced productivity
Better decision making	More reliability
	Advanced customization
	Better maintenance

As it can be seen from Table 7 above, both theoretical and case studies show that data collection, availability of real-time data and enhanced productivity are benefits of IoT technologies on the shop floor.

5.3 Question 3. What are the challenges and issues of implementing IoT into existing businesses?

Using Internet of Things technologies results in generating more data. This data requires to be stored and processed. This large amount of data raises concerns about privacy, data processing, data ownership, communication and standards. Manufacturers will be forced to define and implement new set of standards in order to coordinate and make the devices to work together. Therefore, deploying different approaches such as data structures and communications, considering IoT is necessary for businesses.

Another crucial challenge is about the ownership of the collected data by IoT in different scenarios that involve multiple parties. Typically, copyright agreements are signed to clarify the owner of the produced data by a machine. In case of an IoT object ownership, this object might be owned by a specific company, could be co-owned by several companies or it can be part of a public or private infrastructure. The concern then would be who has the authority to utilize the object and decide on how it is interacting with other IoT objects which requires modification in business model design.

Cyber security is also a concern for the data or systems developed by IoT. The IoT cloud create very sensitive data as well as supporting safety critical systems. It is vital that these systems be safe and secure from intrusion by an unauthorized user or any unintentional data breaches by authorized personnel to handle data.

Companies face many challenges while implementing RFID technologies into factories. The first challenge is tracking the process products and materials in real-time. Second challenge is nonsynchronous communication between inventory control department and manufacturing schedules which results in a backlog of orders and ultimately a time delay. Next one is not being able to forecast life spans, malfunctions which leads to managing systems manually and time delays. And finally, lack of appropriate real-time monitoring system and feedback channel are also big challenges for businesses and shop floor managers. Lack of monitoring system makes it hard to capture information about conditions and failures in the system. Therefore, repair time is delayed.

Raj Batra, president of Siemens Industry’s Automation Division believes the future of manufacturing is in finding the impeccable connection between PLM, MES and industrial automation and learn how to blend them together as a complete system. He states the real issue at Amberg was defining all of the shared points among those three technologies in order to get the sum of that integrated whole. According to Batra, to have a complete system, manufacturers must pull together all of their high-tech tools which is another challenge in itself. (Hessman, 2013) Other general challenges that many factories face in adopting RFID technologies are tag cost and customer nervousness in adopting this new technology. Customers’ reason might be concerns about reader consistency.

At Volvo’s Ghent factory, implementation of IoT technologies is a daily struggle and managers face many challenges. The biggest challenge is the ever changing geography of Ghent’s warehouses and production lines. At the warehouse, wooden containers full of metal parts are stacked up. Those act like walls which move and change frequently. That has a serious negative impact on wireless coverage. And also the factory cannot afford to continually redeploy cables and move access points due to restricted time and advanced planning. Security is also a major challenge. A secure network is a necessity at Ghent due to large amount of automation and proprietary information flowing back and forth. But having a stronger security infrastructure means it is more complex and maintaining successful wireless connections becomes more challenging. Moreover, an ongoing challenge at the factor has been the change in assembly process of some models. The spot on the car body which had been used for the tags so far is not available anymore in the welding shop, because bumper beam will be placed in final assembly shop. As a result, Ghent factory has to relocate the tag during process. Also the transponder is surrounded with integrated electronics such as sensors. It gets significantly harder to guarantee the UHF reading performances that leaves Volvo with the question of which transponder position is optimal for consistent identification.

After answering question 3, the answers provided in theoretical part and case study part are compared in the table below. The shared answers discussed in both theoretical and empirical parts are colored in green.

Table 10. *Barcode and RFID costs at Amberg factory*

Theoretical studies	Case studies
Privacy	Customer trust
Data processing	Matching existing technologies
Data ownership	Continuous changes in factory layout
Communication	Communication
Standardization	Cyber security
Cyber security	Continuous changes in product design
	Data processing

In many cases, it is feasiblefor businesses both technically and financially to employ IoT technologies but there are some challenges on the way such as organizational, institutional and public policy constraints. As it can be seen from table above, although promising, applying IoT technologies in manufacturing is not without its technological and usage challenges. Both theoretical and empirical studies share three important and common challenges that businesses face while implementing IoT technologies.

5.4 Findings and suggested framework

For suggesting this framework, more than 200 articles, journals and press releases are studied. This framework suggests a simplified enterprise architecture which is capable of integrating sensor technologies (particularly RFID), a manufacturing execution system and an enterprise resource planning. The framework also provides practical recommendation on feasibility and cost efficiency of RFID solutions based on previous literature and empirical studies. The recommendations are great help to companies who are making the decision to implement IoT technologies into their facilities. Moreover, it raises important questions about different integration issues which companies have to address when determined to employ RFID technology into their architecture.

During the past two decades IT advancement has been significant and the progress of RFID technologies has been a part of it. This development has provided firms with dazzling productivity gains in different areas. Nowadays some enterprises are benefiting from automated data capturing in their production facilities and supply chains and many enterprises have decided to follow. Of course this brings up substantial challenges such as privacy issues and the idea of an integrated enterprise architecture. However, it brings so many advantages for companies that many are willing to take the risks. For example, it enables factories to track their products or any object inside and outside the plant, starting from production, finishing stages, inventory, distribution, aftersales and even recycling. It is worth mentioning that, this study is mostly focused on production stage on the shop floor of factories.

For companies to successfully integrate RFID technologies into their businesses, they should have an answer for a few important questions. The questions are listed below and the suggested framework in this paper gives answers to these questions.

1. What are the advantages of RFID technologies for the business?
2. Do those advantages outweigh the costs of integration?
3. Which RFID tag collected data should be sent to MES layer?
4. What RFID tag collected data should be sent to ERP layer?
5. Who have permission to reach sensitive information in the enterprise?

Data capturing on the shop floor of factories occurs by RFID readers through sensors. Those RFID readers and sensors are directly connected to computers called “edge servers” and they pass the data on to those computers. Data processing stage is done by edge servers. Companies must have a back-end system to support the company’s back office. In this framework, back-end system collects inputs from shop floor and other systems inside the enterprise such as inventory, orders and supplies for processing. The back-end system consists of edge servers, MES and ERP systems. The suggested framework is represented in Figure 24. Generally, MES control the production process by collaboration with RFID applications. In this suggested framework, MES handles four broad functions inside the plant. These four functions are operations scheduling and production control, labor management, maintenance management and quality management. Below the role of RFID in each function is explained. Overall, this framework demonstrates the integration of IoT technologies into MES and ERP system.

For operations scheduling and production control, materials or containers (objects) on the shop floor are equipped with a tag or in other words a unique ID. The production order data is stored in the RFID tag. In this way, MES makes sure that every step of the production process completes successfully before the object enters the next stage of manufacturing.

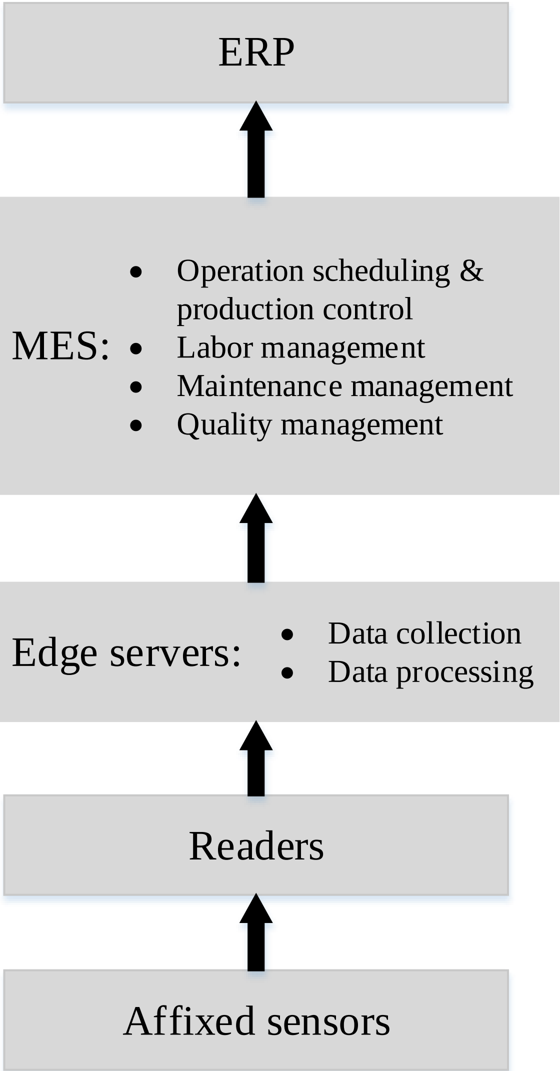

Figure 24. *Suggested integrating RFID, MES & ERP architecture*

For labor management on the shop floor, workers and personnel can be registered by proper sensor technologies and managers are enabled to track them inside the plant. However, this may cause privacy issues and businesses should be extremely cautious about their decisions in this regard. Next function is maintenance management. Maintenance management can minimize quality issues and different sources of loss tremendously. It should be mentioned that in some architectures maintenance is considered as a business process and a part of the ERP system but in this research, it is considered as an operation process. (The reasoning is out of the context of this study) Therefore, from functional point of view, maintenance is part of the MES. The locally stored records in RFID tags can be used to lower the needed paperwork for carrying out maintenance and updating records. And finally, for quality management, the locally stored data of material in tags are used to examine quality targets. The examination involves area functional checks, rework and re-tests, laboratory tests, checking real-time alerting, reporting and corrective actions.

When data passes on to the ERP layer, then ERP can continue with connecting to the suppliers, customers and other partners in the supply chain. Three important outcomes of this suggested framework can be summarized as:

1. More optimized production process due to improved visibility of shop floor and production lines
2. Higher efficiency through having access to real-time data, updated orders and location of materials on the production line
3. Increased readiness to react towards unexpected changes of market and unplanned events

6. CONCLUSION

6.1 Research summary

In the first part of theoretical framework, definition and features of IoT are discussed. The next movement in the era of computing is estimated to be outside the world of desktop. A new paradigm called Internet of Things has grown fast during past few years. (Botta et al., 2016) In chapter 2 various definitions of IoT is presented but the definition chosen for this study is “Interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a common operating picture for enabling innovative applications. This is achieved by seamless ubiquitous sensing, data analytics and information representation with cloud computing as the unifying framework.” (Gubbi et al., 2013)

Then in order to understand the role of IoT in its numerous applications, IoT technologies are categorized into 5 group of radio frequency identification, wireless sensor networks, middleware, cloud computing and IoT application software. Each technology is explained in detail based on scientific research and articles. Also applications of IoT for enterprises are reviewed. The applications are monitoring and control, big data and business analytics, and information sharing and collaboration which are also mentioned in empirical part. Next IoT domains are studied. Gubbi et al. (2013) categorize these applications into four application domains based on type of network availability, coverage, scale, heterogeneity, repeatability, user involvement and impact. They explain how each domain will be impacted by the emerging Internet of Things. The four domains are: (1) Personal and Home IoT at the scale of an individual or home, (2) Enterprise IoT at a community scale, (3) Utilities IoT at the scale of a region or nation and (4) Mobile IoT.

It is predicted that IoT-enabled devices will reach 26 billion units by 2020 and it will impact investors and businesses of all types and consequently affects technologies that are being developed today. Many firms including Microsoft, IBM, Intel and DHL are all investing in the IoT and predict gigantic future growth for IoT. For instance, Business Insider in one of its recent reports forecasts that the IoT will be the largest device market in the world by 2019, overtaking mobile devices and desktop computers combined and create $1.7 trillion in new value. (Fernandez, 2015) IoT creates opportunities and concerns for businesses. IoT will create many opportunities for firms by enhancing data collection, enabling realtime responses, increasing efficiency and productivity, improving access and control of devices, and connecting technologies. Through IoT, frequent data collection will be possible, thus, today’s big data will soon be tomorrow’s little data. It is promised that IoT will change the way we do things but organizations are changing slow due to complicated policy issues such as concerns towards data protection and privacy, ownership of data and standard setting between authorities.

In second part of chapter 2, smart factories, real-time data in ubiquitous manufacturing and challenges of applying RFID technologies in manufacturing are discussed. According to Radziwon et al. (2014), the word 'smart' refers to an independent device, and the device normally includes a sensor, an actuator, a microcomputer and a transceiver. The definition of 'smart factory' chosen for this research is provided by Wang et al. (2016) which is "a manufacturing cyber-physical system[10] that integrates the physical objects such as machines, conveyers and products with the information systems such as MES and ERP to implement the flexible and agile production." Wang believes the smart factory is an essential aspect of Industry 4.0 which offers networked manufacturing systems and the vertical integration for smart production.

Many manufacturing enterprises face common challenges during manufacturing execution. And therefore having access to real-time information helps decision makers to make smarter shop-floor decisions. (Zhang et al., 2015) Real-time data is required in production shop floors of manufacturing firms. Regarding data collection, RFID technology offers a fast and accurate way to collect real-time data from shop floor. Therefore employing RFID technology in the production planning and control has significant benefits. For maximum optimization, there should be a consistent dual-way connection between decision-making level and execution level. RFID tags can be attached to production resources, for instance product component, pallets, machines and operators.

Luo et al. (2015) discusses specifically the challenges shop floor managers encounter while releasing the new orders to shop floor. The first challenge is lack of real-time data feedback channel. When shop floor manager dispatches the orders, the manager does not know what happens in the shop floor until the product reaches the last stage. The second challenge is the lack of information-sharing channel between stages. Sometimes one stage may process jobs faster than other stages and does not control the throughput. This results in unbalanced workloads for each stage. The third challenge is the order delay in peakseason and order earliness in off season. This is due to lack of proper coordination mechanism from the upper level to control the order progress within the whole time horizon.

In chapter 3 both cases of Siemens' Amberg factory and Volvo's Ghent factory are introduced. General information about these cases is provided. It is also explained that why these case are chosen. Siemens Company is the world leader in the market of electronic controls for industrial automation by a significant margin. Siemens' goal for applying IoT technologies in its facilities are getting faster to market, save money in operations, raise productivity throughout the value chain and increasing quality of more complex products. In the eyes of Alessi (2014), Amberg plant is Germany's effort to stay relevant in the digital revolution. During the past few years, VCC has developed its business model to focus on four digital technologies: mobility, social media, analytics and smart embedded devices. Volvo's intention is to strength its connection with the end-customer without interfering with the relationship dealers have with their customers. Volvo's Ghent factory is located in Belgium. Volvo Car Ghent had been developing RFID solutions for past 20 years by investing in research to find a concept that fits their production methods. Ghent's optimized production facility has made it an example factory for other plants.

In chapter 4 both cases of Siemens and Volvo are discussed deliberately. According to Siemens (2015), production at Amberg factory is a custom, built-to-order process, which involves more than 2 billion components for over 50,000 annual product variations. Hessman (2013) explains that the endless variables, extremely complex supply chain and production process at Amberg factory requires capabilities far beyond a traditional factory. Over the course of 25 years, Amberg plant has enhanced its reliability to almost perfection and this happened throw automation. In 1990, only 25 percent of the shop floor was automated. Siemens' managers decided to move the factory towards a more automated future; today, 75 percent of the shop floor at Amberg factory is automated.

Smart integration at Amberg is elaborated in chapter 2. Siemens integrates three specific manufacturing technologies of product lifecycle management, manufacturing execution systems and industrial automation. Siemens' definition of PLM is "an information management system that can integrate data processes, business systems and ultimately, people in an extended enterprise." According to Omer (2014), industrial automation is defined as "a set of technologies that results in operations of industrial machines and systems without significant human intervention and achieve performance superior to manual operation." And finally, MES is the link between the production and management levels which provides higher transparency throughout the plant. In other words, MES is the core element connecting PLM to Automation.

Next, the paper has looked deeply into IoT at Amberg. At the facility, engineers have utilized IoT technologies to implement a self-organizing production which prioritizes and enters jobs into the production network. The production employs specific work-piece carriers which are well equipped with Siemens own RFID transponders. It enables data to be retrieved remarkably fast, and therefore the work-piece does not have to stop at the reader. Through RFID chip, workers receive precise instructions on the touchscreens regarding what to do with specific work-piece.

In the second part of chapter 4, Volvo's plant in Ghent is analyzed. One of the largest assembly plants in the portfolio of Volvo Cars Corporation is Ghent factory. It assembles more than 35,000 vehicles per year. The factory uses technology for instant request of refilling parts on the line. Also Ghent owns a large fleet of Automated Guided Vehicles (AGVs) driving around the facility with chassis which are equipped with wireless trackers and sensors and fully connected by antennae. (iMinds, 2014) The controllability of a factory is greatly dependent on the interaction between enterprise resource planning system and shop floor, and the capability of any authorized user to review the status of sales orders on the shop floor. At Ghent, the production is even more complicated than other plants because several different models are assembled in the same production line. That is why Ghent factory relies on IoT applications to identify and reliably track every car during the whole production process to manage such a variety of products. And in the last part of chapter 4, challenges and benefits of IoT at Ghent factory is discussed. Those challenges include privacy, changing layout of the factory and changing design of the products. Some of the benefits are more reliable production, optimized plant and availability of real-time data.

Chapter 5 is the part that the questions asked in the objective sections are answered properly. Each question is answered based on both literature review and empirical review and then those two answers are compared in a table. Last part of chapter 5 is findings and suggested framework. This study offers a practical framework for companies validated to integrate RFID technologies into their businesses. It raises questions for companies to consider and also points out the benefits of implementing this framework. Chapter 6 includes a research summary of thesis, limitations and validity and also future research and recommendations.

6.2 Limitations and validity

This research is a multiple-case studies. According to Yin (2003), "A multiple case study enables the researchers to explore differences within and between cases. The goal is to replicate findings across cases. Because comparisons will be drawn, it is imperative that the cases are chosen carefully so that the researcher can predict similar results across cases, or predict contrasting results based on a theory." Yin suggests three principles for data collection which are use of multiple sources of evidence, create a case study database and maintain a chain of evidence.

This study had some limitations. The level of integration of IoT technologies in each case study is different, therefore cases couldn't be compared in every aspect. Also the case study method can be very subjective which may lead to misunderstanding and errors due to the researcher's interpretations. The topic of this research is very new and there are less published sources and materials available to use. A verification of the results by key employees of selected case studies could provide useful feedback as well as make the study more credible. Moreover, complementing the findings of the study with interviews and companies internal information would have increased the validity of the results. Data collection of this study has followed Yin's principles. The validation of the study was improved by applying several means. The case selection criteria fully support the research objectives and the cases are cautiously selected. The validity of this research is increased by using multiple up-to-date sources. Throughout the paper, chain of evidence is kept by carefully recording data and using the most relevant sources for each topic.

6.3 Recommendation and future research

In the world where IoT is used for problem solving, technology takes on a more noticeable presence. As companies more rely on machine-to-machine communication, interaction and decision making, there will be less human involvement in many IoT related actions. This results in higher security risks. Therefore, this paper strongly recommend companies with plans to integrate IoT technologies into their businesses to carefully take privacy and security issues into consideration.

It is highly recommended that companies determined to implement IoT in their facilities, should well prepare their employees beforehand. As this paper studies the company of Volvo, it was apparent that Volvo's personnel had a hard time to adopt themselves to the new IoT approach. Even in the managerial level, the struggle was real, since connecting with end-customer was not something that Volvo was used to. Therefore, it is in businesses benefits to raise their skillset and understanding of IoT.

In terms of feasibility and cost efficiency of RFID solutions for businesses, it is recommended that companies notice the following issues:

- Typically, high-volume, low-cost goods do not make up for the cost of implementing RFID solutions.
- If the size of companies' product is very small that it cannot support a tag, then tracking and tracing would be an issue for the firm. The company must look for other technologies to employ.
- Companies must address the issue that combining RFID and location sensing technologies such as Global Positioning system (GPS) is not always enough to locate the materials on the production line. Thus, three-dimensional position tracking might be needed.
- Frequent changes in the design of products might become a serious challenge for the company. Based on the findings from Volvo's Ghent factory, transformation of products makes it hard to affix the tag on the products and ultimately makes the tracking and collecting real-time data harder.
- In order to have a profitable operation, it is highly recommended that companies think about whether they want to tag every individual item on the production line or tag carrier devices. The cost difference between these two approaches is gigantic. (Gunther et al., 2008)

For every company that decides to invest into IoT, the potential financial returns is the most important factor. Thus, companies constantly require new business models and ways to create value for IoT technologies. For future research, studying business models for adopting IoT technologies has great potential. (Dijkman et al., 2015)

Another topic for future study is IoT cost-benefit analysis. Since the adoption of IoT technologies is at a fast pace, companies faces many uncertainties in regards to potential benefits and high investments costs. Therefore, cost-benefit analysis of IoT technologies is an excellent topic to work on.

Finally, as every manufacturer's goal is to have a more optimized production process, the role of MES and ERP in facilities can be an interesting topic for future studies. There are many misunderstanding and disagreement about MES and ERP duties in an enterprise. Thus, elaborating on the tasks of these two systems in an enterprise architecture can be a topic for future study.

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